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APPENDIX H

HYDROLOGIC MEASUREMENTS ON TYPICAL SOILS IN THE GOODWIN CREEK CATCHMENT

Project Objectives 3 and 4

by

M. J. M. Römkens

USDA Sedimentation Laboratory
Oxford, Mississippi

April 1981

Prepared for
US Army Corps of Engineers, Vicksburg District
Vicksburg, Mississippi

Under
Section 32 Program, Work Unit 7

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and

F. D. Whisler[2]

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PREFACE

The hydrologic response of typical soils in the Goodwin Creek catchment was investigated. Studies consisted of two types of measurements. First, the drainage and evaporation characteristics of three upland soils (Grenada, Loring, Memphis) and one bottomland soil (Vicksburg) were examined on isolated blocs of initially wet soil profiles. Pressure head and hydraulic head relationships were established at various dates following dissipation of the test dose of surface applied water. The change in the total water content of the profile with Lime was computed to determine the subsurface drainage characteristics. For the Grenada soil the in situ hydraulic conductivity was ~~also~~ determined. This study was supplemented with limited infiltration experiments under ponded surface conditions. Secondly, the soil water regime in bottomland watersheds cropped to cotton was measured for two consecutive years. The purpose of the latter study was to determine the effect of soil water storage on the water budget for unit source watersheds on bottomland areas. Data indicate poor internal drainage characteristics of the upland soils. Runoff hazards are large, especially under wet antecedent conditions. Internal drainage in the tested bottomland soil was nearly an order of magnitude larger than those of the upland soils. The water content measurements on the bottomland unit source watershed showed a typical decline in soil water during the summer months due to evapotranspiration. It also showed the effect of a "genetic" pan on soil water storage. The data suggests reduced infiltration rates and increased runoff hazards during the wet season.

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) AND METRIC (SI) TO U.S. CUSTOMARY UNITS OF MEASUREMENT 1/

Units of measurement used in this report can be converted as follows:

To convert	To	Multiply by
mils (mil)	micron (μm)	25.4
inches (in)	millimeters (mm)	25.4
feet (ft)	meters (m)	0.305
yards (yd)	meters (m)	0.914
miles (miles)	kilometers (km)	1.61
inches per hour (in/hr)	millimeters per hour (mm/hr)	25.4
feet per second (ft/sec)	meters per second (m/sec)	0.305
square inches (sq in)	square millimeters (mm^2)	645.
square feet (sq ft)	square meters (m^2)	0.093
square yards (sq yd)	square meters (m^2)	0.836
square miles (sq miles)	square kilometers (km^2)	2.59
acres (acre)	hectares (ha)	0.405
acres (acre)	square meters (m^2)	4,050.
cubic inches (cu in)	cubic millimeters (mm^3)	16,400.
cubic feet (cu ft)	cubic meters (m^3)	0.0283
cubic yards (cu yd)	cubic meters (m^3)	0.765
cubic feet per second (cfs)	cubic meters per second (cms)	0.0283
pounds (lb) mass	grams (g)	454.
pounds (lb) mass	kilograms (kg)	0.453
tons (ton) mass	kilograms (kg)	907.
pounds force (lbf)	newtons (N)	4.45
kilogram force (kgf)	newtons (N)	9.81
foot pound force (ft lbf)	joules (J)	1.36
pounds force per square foot (psf)	pascals (Pa)	47.9
pounds force per square inch (psi)	kilopascals (kPa)	6.89
pounds mass per square foot (lb/sq ft)	kilograms per square meter (kg/m^2)	4.88
U.S. gallons (gal)	liters (L)	3.79
quart (qt)	liters (L)	0.946
acre-feet (acre-ft)	cubic meters (m^3)	1,230.
degrees (angular)	radians (rad)	0.0175
degrees Fahrenheit (F)	degrees Celsius (C) 2/	0.555

2/ To obtain Celsius (C) readings from Fahrenheit (F) readings, use the following formula: C = 0.555 (F-32).

Metric (SI) to U.S. Customary

To convert	To	Multiply by
micron (μm)	mils (mil)	0.0394
millimeters (mm)	inches (in)	0.0394
meters (m)	feet (ft)	3.28
meters (m)	yards (yd)	1.09
kilometers (km)	miles (miles)	0.621
millimeters per hour (mm/hr)	inches per hour (in/hr)	0.0394
meters per second (m/sec)	feet per second (ft/sec)	3.28
square millimeters (mm^2)	square inches (sq in)	0.00155
square meters (m^2)	square feet (sq ft)	10.8
square meters (m^2)	square yards (sq yd)	1.20
square kilometers (km^2)	square miles (sq miles)	0.386
hectares (ha)	acres (acre)	2.47
square meters (m^2)	acres (acre)	0.000247
cubic millimeters (mm^3)	cubic inches (cu in)	0.0000610
cubic meters (m^3)	cubic feet (cu ft)	35.3
cubic meters (m^3)	cubic yards (cu yd)	1.31
cubic meters per second (cms)	cubic feet per second (cfs)	35.3
grams (g)	pounds (lb) mass	0.00220
kilograms (kg)	pounds (lb) mass	2.20
kilograms (kg)	tons (ton) mass	0.00110
newtons (N)	pounds force (lbf)	0.225
newtons (N)	kilogram force (kgf)	0.102
joules (J)	foot pound force (ft lbf)	0.738
pascals (Pa)	pounds force per square foot (psf)	0.0209
kilopascals (kPa)	pounds force per square inch (psi)	0.145
kilograms per square meter (kg/m^2)	pounds mass per square foot lb/sq ft)	0.205
liters (L)	U.S. gallons (gal)	0.264
liters (L)	quart (qt)	1.06
cubic meters (m^3)	acre-feet (acre-ft)	0.000811
radians (rad)	degrees (angular)	57.3
degrees Celsius (C)	degrees Fahrenheit (F)[3/]	1.8

1/ All conversion factors to three significant digits.

3/ To obtain Fahrenheit (F) readings from Celsius (C) readings, use the following formula: $F = 1.8C + 32$.

Notation

A	Profile thickness	L
H	Total soil water potential	L
K	Hydraulic conductivity	LT^{-1}
Q	Total water content of soil profile per unit area	L^3L^{-2}
V_{dr}	Drainage flux	LT^{-1}
V_{ev}	Evaporation flux	LT^{-1}
V	Flux	LT^{-1}
c	Arbitrary position in profile	L
t	Time coordinate	T
z	Position coordinate	L
i	Subscript variable for time	
j	Subscript variable for position	
θ	Volumetric water content	L^3L^{-3}
§	Dummy variable	L
Ψ	Matrix potential	L

1 INTRODUCTION

Large scale denudation of the Bluffs along the Mississippi River during and following settling in the nineteenth century led to significant changes in the surface hydrology of Bluff line watersheds. The increased volume, rates, and peak discharges accelerated many times over the then prevailing geological soil erosion and sediment transport rates. Headcuts and bank failures widened and deepened the channels in the process of accomodating increased flow rates. Details of the nature and causative factors of these channel problems are discussed elsewhere in this report. This particular chapter deals with the impact of the soil water regime, of major soils in the Bluff line watersheds, as it relates to internal drainage, infiltration, and thus the discharge rate of excess rain water into the existing channel system.

Numerous factors influence the rate and amount of excess rain water and its discharge into channels for subsequent conveyance to larger rivers. They include rainfall, rainfall rate, antecedent conditions, cover, topography, soils, etc. At a given location the excess water available for runoff is determined by the balance of rainfall, surface storage, and infiltration. The latter process depends on such factors as soil type, soil water antecedent conditions, rainfall history and evapotranspirative demand by the prevalent canopy. Often, the summer periods are characterized by a net water loss because of evapotranspirational processes, whereas the late fall, winter, and early spring usually yield water surplus. Therefore, it may be concluded that soil type and the hydraulic characteristics will significantly affect the surface water regime.

In transecting the Bluff Line region from east to west, three land resource areas are encountered. Each of these land resource areas has its own soil groupings (Vanderford, 1962). A cross-sectional view through these land resource areas is given in Fig. 1. At the foot of the Bluffs is the Mississippi Delta. Its soils consist of alluvial material, which was deposited either by the Mississippi River or represents washin-in from tributaries draining the watersheds on the Bluffs. The soils of the Bluff

region itself belong to the Brown Loam (thick loess) belt and are mostly of aeolic origin. They are over 120 cm (4 ft) thick and high in silt content. They are, therefore, subject to severe erosion hazards. Hard pans or impervious layers are common occurences. Soils, having hard pans, are usually classified as fragiudalfs. Further to the east, the third land resource area is encountered. It is made up of soils belonging to the Thin Loess Area. Its soils are generally less than 120 cm (4 ft) thick and silty in composition. They represent a transitional belt between the soils of the Brown Loam to the west and the Coastal Plain soils to the east. The underlying coastal plain material has significantly influenced soil profile development in this belt. Erosion hazards are severe with gully erosion being a serious problem. Many of the unit source watersheds draining the Bluffs originate in this belt. The major part of the Goodwin watershed is located in the Brown Loam land resource area.

In assessing the role of soils in the Brown Loam land resource area on the surface hydrology of the Goodwin basin, the hydraulic characteristics of typical profiles need to be examined. Several major soil series found in this basin were selected for an in-depth study. The soils selected consisted of three upland soils (Grenada, Loring, and Memphis) and one bottom land soil (Vicksburg). The Grenada (Fragiudalf) is considered to be a moderately well drained soil with a genetic pan at about 55 to 60 cm (22 to 24 inch) depth. The Loring (Fragiudalf) is a deep soil with a weak pan at about 67 to 72 cm (26 to 28 inch) depth. The Memphis (Hapludalf) is a deep, well drained soil without a pan. Vicksburg is a well-drained bottomland soil without a genetic pan. However, as a bottomland soil, it has usually been in cultivation, mostly in cotton or soybeans, and thus may have developed a plow pan. Except from general physical principles, the impact of this pan on infiltration and water movement has not been clearly established. Grenada, Loring, and Memphis are, as upland soils on rolling slopes, usually seeded to pasture. Unless occasionally tilled, they may possess a compacted top layer due to cattle traffic. Fig. 2 represents a cross-section through a channel area and depicts the relative position of some of the aforementioned soils in the landscape.

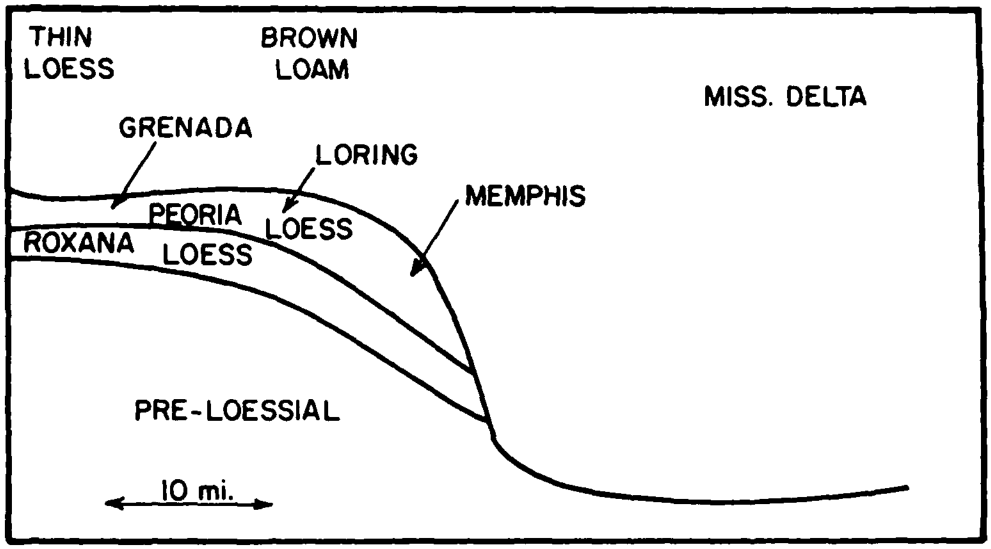

Figure 1 A cross-sectional view through the various land resource areas

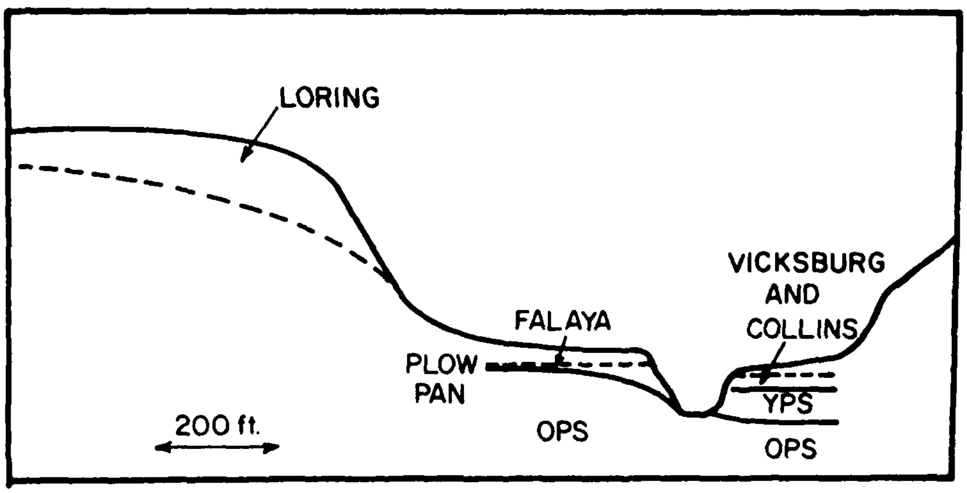

Figure 2 A cross-section through a valley.

Research objectives as implemented under this project were two-fold: (i) to examine the hydrologic behavior of the aforementioned soils either under evaporative or drainage conditions, (ii) to follow the soil water regime in bottomland watersheds during the crop growing season. These objectives deviate from those of the original proposal in that they represent a significant expansion of the original scope of the project. This report will furthermore indicate how the information can be used to compute *in situ* values of hydraulic conductivities in the near saturated region. This information, under certain conditions, may be necessary in determining ponding times during rainstorm events. On some soils (Loring, Memphis, Vicksburg) preliminary infiltration studies were conducted, however, more significant efforts in this regard will be conducted during the 1981 and 1982 summer season.

2.1 THEORY

Water movement at any point in the soil profile is described by Darcy's law:

$$V = -K(\Theta)\cdot\text{grad }(H) \tag{1}$$

where V is the flux in $cm\cdot sec^{-1}$, K is the hydraulic conductivity which is a function of the moisture content, and H is the total soil water potential. Latter potential is usually described as the sum of two component potentials namely the gravitational potential, z, and the pressure or matrix potential $\Psi(\Theta)$ according to the relationship:

$$H = \Psi(\Theta) + z \tag{2}$$

If combined with the continuity equation

$$\frac{\partial\Theta}{\partial t} = -\text{ grad }(V) \tag{3}$$

a non-linear partial differential equation is obtained, commonly called the Richards' or diffusivity equation, which for one-dimensional flow can be written as

$$\frac{\partial\Theta}{\partial t} = \frac{\partial}{\partial z}\, K(\Theta)\, \frac{\partial\Psi(\Theta)}{\partial z} + \frac{\partial K(\Theta)}{\partial z} \tag{4}$$

Depending on the complexity of the relevant boundary conditions and the nature of the $K(\Theta)$ relationship, either a closed form or numerical solution may be obtained. However, in all cases knowledge of the conductivity-moisture content relationship and the pressure head-moisture content is a prerequisite for solving the flow problem at hand.

In many field situations such as described in this setting, neither the aforementioned relationships are available nor is a simple application of equation (4) realistic, because of (i) the inherent presence of multilayered soil systems, in which different $k(\Theta)$ and $\Psi(\Theta)$ relationships apply to each soil horizon, and (ii) the non-ideal response of the soil to water transmission due to changes in the soil matrix (swelling, shrinking). Unless one resorts to direct field measurements, the total impact of a natural, multi-layered soil profile on water transmission and infiltration is difficult to establish. These field measurements should consist of

either measurements of fluxes or computed fluxes from measured hydraulic gradients and known conductivities. In either case, an appropriate boundary condition must be selected with respect to which measurements and computations are made.

The approach chosen in this study consisted of establishing, for an isolated block of soil, a zero flux boundary condition either at the soil surface (drainage) or at some distance into the soil profile (evaporation from the soil surface and drainage to deeper horizon). Drainage and evaporative fluxes are then computed relative to the zero-flux boundary.

The total water content between a point c in the soil profile and the zero-flux plane z(t) can now be given by the relationship:

$$Q(z,\ t) = \int_{\S=z(t)}^{\S=c} \Theta(\S,\ t)\ d\S \tag{5}$$

where $\S = z(t)$ represents the position of the zero-flux boundary at time t and $\Theta(\S,t)$ is the moisture content. The total water content of an A-cm thick soil profile is given by:

$$Q(A,t) = \int_{\S=0}^{\S=A} \Theta(\S,t)\ d\S = f(t) \tag{6}$$

The flux-out of a A-cm thick soil profile by both drainage and evaporation can be given by the relationship:

$$V_{dr} + V_{evap} = \frac{dQ(A,t)}{dt} = \frac{d}{dt}\left[\int_{A}^{\S(t)} \Theta(\S,t)d\S + \int_{\S(t)}^{0} \Theta(\S,t)d\S\right]$$

which according to Leibnitz's rule (Hildebrand, 1963) yields:

$$V_{dr} + V_{evap} = \int_{A}^{\S(t)} \frac{\partial\Theta(\S(t),t)}{\partial t}\ d\S + \Theta(\S(t),t) \cdot \frac{d\S(t)}{dt} +$$

$$\int_{\S(t)}^{0} \frac{\partial\Theta(\S(t),t)}{\partial t}\ d\S - \Theta(\S(t),t) \cdot \frac{d\S(t)}{dt} \tag{7}$$

For a drainage profile of thickness A with a zero-flux boundary condition at the soil surface the right hand side of equation 7 reduces to:

$$V_{dr}(A,t) = \frac{d}{dt}\int_{§=A}^{0}\Theta(§,t)d§ = \frac{dQ(A,t)}{dt} \tag{8}$$

The finite difference form of equation (8) can be written as follows:

$$V_{dr}(A,t) = \frac{1}{\Delta t}\sum_{j=1}^{n}\{\Theta(§_{j-\frac{1}{2}},t+\Delta t) - \Theta(§_{j-\frac{1}{2}},t)\}(§_j - §_{j-1}) \tag{9}$$

where n represents the number of mathematical grids imposed on the soil profile of thickness A.

Similarly, the average water content of the soil layer between z_j and z_{j-1} can be computed according to the relationship:

$$\bar{\Theta}(z_{j-\frac{1}{2}},t) = \frac{Q(z_{j+1},t) - Q(z_j,t)}{z_{j+1} - z_j} \tag{10}$$

The hydraulic conductivity of a soil horizon can now be computed from the flux as determined by equation (9) and the observed difference in hydraulic head across a soil horizon. Practical considerations dictate that these measurements be made between two tensiometer positions within a soil horizon. The hydraulic conductivity can be expressed as follows:

$$K(z_j \to z_{j-1},t_i) =$$

$$\frac{[Q(z_j,t_i)-Q(z_j,t_{i-1}) + Q(z_{j-1},t_i) - Q(z_{j-1},t_{i-1})]}{2(t_i - t_{i-1})} \times$$

$$\frac{2(z_j - z_{j-1})}{H(z_j,t_i)-H(z_{j-1},t_i) + H(z_j,t_{i-1}) - H(z_{j-1},t_{i-1})} \tag{11}$$

where the first fraction on the right hand size of eq. (11) represents the average flux in interval z_j and z_{j-1} and the second fraction represents the average hydraulic gradient during time interval $t_{i-1} \to t_i$.

Computations of fluxes and conductivities for water movement in soil profiles where simultaneously, evaporation at the soil surface and drainage in the deeper part of the profile occurs, can also be handled by eqs. (10) and (11). However, the shifting position of the zero-flux plane should be properly defined at all times.

Soil variability as well as sampling errors can often lead to significant variations in the integrated water content of the soil profile or part thereof. In order to make realistic estimates of fluxes, especially for slowly draining soil profiles, the observed integrated water content data need to be smoothed. Various functional relationships can be fitted to the observed data. Some of the more common functions considered in this study are linear, exponential, asymptotic and power functions. The coefficients in these equations are functions of depth. The relationship which yields the smallest value of the standard error of the estimate may then be chosen for flux computation across a plan §=z during time interval t_i and t_{i-1}. Similarly, smoothing of tensiometer readings are necessary, especially in slowly draining soil profiles, in order to eliminate random errors in tensiometer data.

2.2 EXPERIMENTAL PROCEDURE

The experimental procedure chosen was a modification of that described by Cassel (1975). This procedure consisted of isolating a block of soil from the surrounding soil mass, and ponding the plot surface with water until the soil profile was thoroughly wetted. Soil water content and soil water potential measurements were then made at frequent time intervals during either a drainage or an evaporative phase. Hydraulic gradients, fluxes, and hydraulic conductivities were then computed.

2.2.1 Site Information

The Grenada site was part of an area (9 by 9 m) located in the SW¼ of the SW¼ of Sect. 28, T7S, R4W, Lafayette County, MS. The area is part of the flood plain of Sardis Lake Reservoir. This site frequently floods during sustained wet periods in the winter, spring and early summer. The area was planted to soybean in the previous growing season. Generally, the area is planted to soybean, millet, or it has a natural vegetative cover depending on the *de facto* flood control operation of Sardis Lake Reservoir. The slope was 1-2% and the topography was gently undulating.

The Loring site was part of an area (15 x 15 m) located in the SW¼ of the SE¼ of Sect. 16, T9S, R6W, Panola County, MS. The site is part of a field which had been for years in pasture with Bermuda grass. The site was located on a relatively flat part of a severely eroded slope of 5 to 8%. The land capability class of this soil is III.

The Memphis site was part of an area (15 x 15) located in the NE¼ of the SE¼ of Sect. 19, T8S, R7W, Panola County, MS. The site is part of a field which had been for years in pasture with Bermuda grass. The research plots were located on a relatively flat part of a severely eroded slope of 5 to 8%. The land capability class is III.

The Vicksburg site was part of an area (15 x 15 m) located in the NE¼ of the NE¼ of Sect. 31, T9S, R6W, Panola County, MS. This site is located in a 1.6 ha bottomland field cropped to cotton. The research plots, which had a 0.2% slope, were immediately adjacent to Goodwin Creek opposite the Good Hope Baptist Church, north of Eureka Springs.

Only the Loring and Vicksburg sites were located in the Goodwin watershed study area proper. The selections of the Grenada and Memphis sites were dictated by site availability and cooperation of land owners. A profile description[1/] for each soil is given in appendix A.

2.2.2 Plot Information

The 2.10 x 1.80 m plots on the Loring, Memphis, and Vicksburg sites and the 3.66 x 1.80 m plots of the Grenada site were isolated from the surrounding soil mass by 60 cm (2 ft) wide trenches of 1.25 m (50 inches) depth. A schematic cross section through a plot is shown in Fig. 3. The vertical side walls of the plots were coated with a 2-3 cm (1 inch) thick layer of concrete, prepared from a 1:1 mixture of mortar mix and sand. For some plots of the Loring site and all plots of the Vicksburg soil, the floor of the trench was also covered with concrete to further minimize external influences on the water regime within the plots. The concrete wall was subsequently coated with epoxy paint to eliminate evaporative losses through the cement wall. Four access tubes for soil water content determinations were installed in each plot. The 5.08 cm (2 inch) diameter tubes reached a depth of about 1.60 m (5 ft) and extended 7.5-10 cm (3-4 inches) above the soil surface. Access tubes were located on the diagonals at about 75 cm from each corner of the plot (Loring, Memphis, Vicksburg). Only two access tubes, randomly positioned, were used for water content measurements on the Grenada site. This approach insured an adequate

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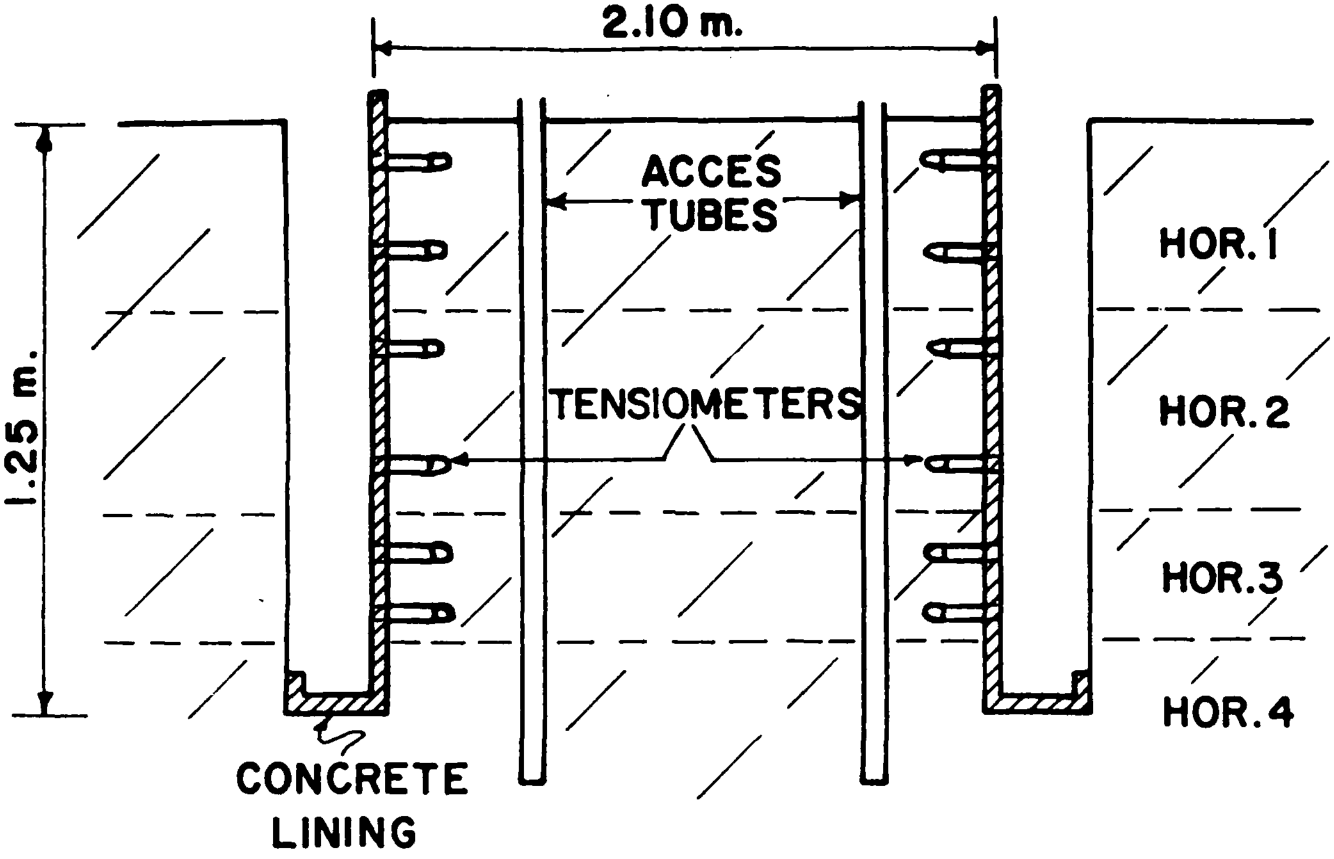
1/ Soil profile descriptions were prepared by Mr. W. M. Morris, Jr., District Soil Scientist, USDA-SCS, Lafayette County, MS.



Schematic cross-section of experimental plot.

accounting of the soil water content of the entire plot during subsequent water content determinations with a neutron probe.

A tensiometer set was placed in the center of each wall. Each tensiometer set consisted of 9 to 12 tensiometers. Tensiometers were inserted horizontally to a depth of 20 to 25 cm (8 to 10 inch) into the sides of the plot. At least 2 tensiometers per set were placed within each horizon, preferably near the horizon boundaries. The tensiometers consisted of 1.91 x 6.67 cm straight wall porous cups, which were sealed at the open end with a rubber stopper (size 00). The rubber stoppers were perforated with two stainless steel tubes, to which 2.4 mm O.D. with 0.4 mm wall thickness nylon tubing was attached. One tube was connected to a mercury reservoir for matric potential readings, the other was sealed off with another stainless steel tube inserted into a rubber stopper. The latter tube permitted periodic purging of air from the tensiometer.

Over all plots including the trenches, a gable type roof was constructed to protect the study site from rainfall. The gable front and rear sides were largely left open to promote air circulation.

2.2.3 Procedure

Vegetative growth on the plot surface was eliminated by surface spraying with paraquat. The plot surface was leveled as much as possible and left in an untilled condition.

The large plot size precluded an accurate assessment of the amount and rate of water intake. The procedure selected in this study consisted of intermittent flooding of the plot surface for a period of 4 to 6 days, thereby maintaining as much as possible a ponded surface condition. Water application to the soil surface was ceased when tensiometer readings throughout the profile appeared to give nearly constant values. Experimental observations were commenced following the near complete surface drainage of the last dose of surface applied water. Plots were either sealed off at the surface (drainage mode) or were left uncovered (evaporation mode). The drainage plots were covered with one sheet of black plastic followed by a 5 cm (2 inch) thick layer of insulation material (styrofoam or water repellent building insulation material) and another sheet of black plastic. The holes in the plastic through which the access tubes protruded were sealed off with electrical insulation tape. The entire plot surface, including the protruding access tubes, was covered

with another plastic sheet to further reduce evaporation losses. A slightly different sealing procedure was used on the Grenada site, which was first investigated. Here water repellent insulation material directly covered the soil surface. As will be discussed later, this had significant consequences regarding the water regime in the plot, during the study period. Following completion of the experiment, the plots were broken up and soil cores were taken for both bulk density determinations and soil water desorption data.

Measurements consisted of water content determinations and tensiometer readings at regular time intervals. Duplicate (Grenada) or triplicate (Loring, Memphis, Vicksburg) gravimetric determinations were made at 2.5 cm intervals up to a depth of 109 cm for the Grenda plots and 122 cm for all other plots. During gravimetric samplings the plot surface was partially uncovered to permit sample extraction. The repeated exposures may have led to some evaporation losses at the soil surface as was noticed in a number of cases. The gravimetric measurements were converted to volumetric values using bulk density - depth relationships as a basis for conversion.

The 3 x 5.1 cm bulk density cores were taken in duplicate (Vicksburg) or in quadruplets (Grenada, Loring, Memphis) from the soil area between consecutive tensiometer positions. Water content determinations were also determined according to the neutron thermalization technique. Duplicate measurements were made on plots of the Grenada site, while quadruplet measurements were performed on all other plots.

Soil material from each horizon was taken for analysis of textural composition. Table 1 summarizes pertinent research information for the selected research sites. Table 2 summarizes the textural composition for each soil horizon.

2.3 RESULTS AND DISCUSSION

2.3.1 Grenada Site

The water content information used for this site is based on gravimetric sampling up to a depth of 106.0 cm. A typical example of the experimental detail with which water content measurements were made on all plots is given in Fig. 4. The bulk density-depth relationship is given in Fig. 5. Three regression equations describe the change in bulk density with depth with discontinuities at 6 and 48 cm. The discontinuities coincide with the transitions from the Ap to Ap1 horizon and from the B22

Table 1. Information summary for the selected research sites.

Site	Plot Number	Mode[1] of Water Mov.	Study date[2] Yr.	Months	Duration Hrs.	Number of Samplings Water	Number of Samplings Tens.	Ten. Sets	Soil Water Samplings per date Neutron	Soil Water Samplings per date Grav.	Ponding time, hrs.
Grenada	1	Drain	1978	Sept.-Dec.	1916	18	18	3	2	2	168
	2	Drain	1978	Oct.-Dec.	1080	11	11	3	2	2	168
Loring	1	Evap.	1979	July-Sept.	1441	20	23	4	4	3	264
	2	Drain	1979	Aug.-Nov.	2137	18	21	4	4	3	221
	3	Drain +	1979	July-Sept.	1512	20	30	4	4	3	98
	3	Evap.	1979	Oct.-Nov.	1428	11	18	4	4	3	125
Memphis	1	Drain	1979	Sept.-Dec.	1405	18	23	4	4	3	100
	2	Evap.	1979	Sept.-Dec.	1564	15	18	4	4	3	100
Vicksburg	1	Drain	1980	July-Aug.	900	14	30	4	4	3	100
	2	Drain	1980	July-Aug.	800	15	27	4	4	3	100
	3	Drain	1980	July-Aug.	624	15	23	4	4	3	100

1 Represent the intended water movement mode.

2 Represents the period in which field observations were made. It does not include plot preparational activities, core sampling and other plot characterization activities.

Table 2. Textural composition of the soil horizon for each research site.

Site	Horizon	Depth cm	2-1 mm	1-0.5 mm	0.5-0.25 mm	0.25-0.105 mm	0.105-0.05 mm	Sand %	Silt %	Clay %
Grenada	Ap	0-8	0.0	0.2	1.0	1.3	0.6	4	79	17
	Apl	8-13	0.0	0.2	1.1	1.5	0.5	3	80	17
	B21	13-	0.0	0.1	0.6	0.8	0.5	3	76	21
	B22	52								
	A'2	52-62	0.0	0.1	0.6	0.7	0.5	3	77	20
	B'x	62-152	0.0	0.1	0.4	0.8	0.5	2	76	22
Loring	Ap	0-8	0.1	0.2	0.5	0.4	0.3	1.5	74.4	24.1
	B21+	8-59	0.0	0.0	0.1	0.1	0.1	0.3	72.9	26.8
	B22+	59-91	0.0	0.1	0.3	0.2	0.2	0.8	79.4	19.8
	Bx	91-122	0.0	0.1	0.7	0.7	0.4	1.9	80.4	17.7
Memphis	Ap	0-13	0.0	0.1	0.2	0.2	0.4	0.9	80.5	18.6
	B21t	13-69	0.0	0.0	0.0	0.1	0.2	0.3	70.5	29.2
	B22t	69-104	0.0	0.0	0.0	0.0	0.2	0.2	77.1	22.7
	B3t	104-127	0.0	0.0	0.0	0.1	0.2	0.3	79.5	20.2
Vicksburg	Ap	0-18	0.0	0.3	3.9	6.5	1.4	12.1	78.8	9.1
	C1	18-23	0.1	0.9	7.8	10.4	1.5	20.7	70.5	8.8
	C2	33-63	0.0	0.1	7.2	11.3	1.9	20.5	69.4	10.1
	C3	63-81	0.2	0.7	7.7	13.2	1.7	23.5	66.1	10.4
	C4	81-124	0.0	0.1	3.2	6.2	1.7	11.2	74.8	12.9

to A'2 horizon, respectively. The latter discontinuity appears to reflect a significant change in the stratigraphy of this profile. The increase represents the onset of a "genetic" pan or different stratigraphic layer, which appreciably affects the water regime of the soil profile. Its influence can readily be seen in Fig. 7, which shows the relationship between hydraulic head and soil depth at various sampling times following ponding. Several observations can be made. Immediately after ponding, a significant drainage gradient is noted throughout the soil profile with the largest gradient at the pan level. With the passage of time an evaporative gradient developed with the largest magnitude again in the zone of the pan. Secondly, the magnitude of the hydraulic head at 90 cm. of depth and beyond, does not significantly change over a 1200-hr. period. This suggests that the pan region hardly conducts water. Thirdly, the hydraulic head profile in the soil region above the pan is nearly vertical suggesting a quasi-equilibrium condition in this part of the soil profile. At 719 hrs following ponding a slight increase in the gradient is noted in favor of water movement out of the soil profile.

The effect of the pan on the soil water regime can also be seen in Fig. 6, where the relationship between pressure head and soil depth at various times following ponding is shown. For about 6 days following ponding a positive pressure is noted immediately above the pan. This pressure dissipated gradually with time. However, the pressure head within the pan itself remained negative. The free standing water above the fragipan apparently dissipated largely by lateral movement to the plot sides where it seeped through cracks, holes, and channels between the cement wall and the soil block to the bottom of the trench. This was evident by the accumulation of water in the trench for a number of days following the last surface application of water. The implications of this finding are very significant in that appreciable amounts of lateral flow may occur, when these type soils occur on sloping fields. Moreover, the potential hazard for incipient rilling and gullying at exit points is increased, especially when these exit points coincide with low places in a field where surface water (runoff) concentrates.

The nearly vertical or constant hydraulic head above the pan itself reflects the near of pseudo-equilibrium condition of soil water within this part of the soil profile. It follows that frequent and careful readings of

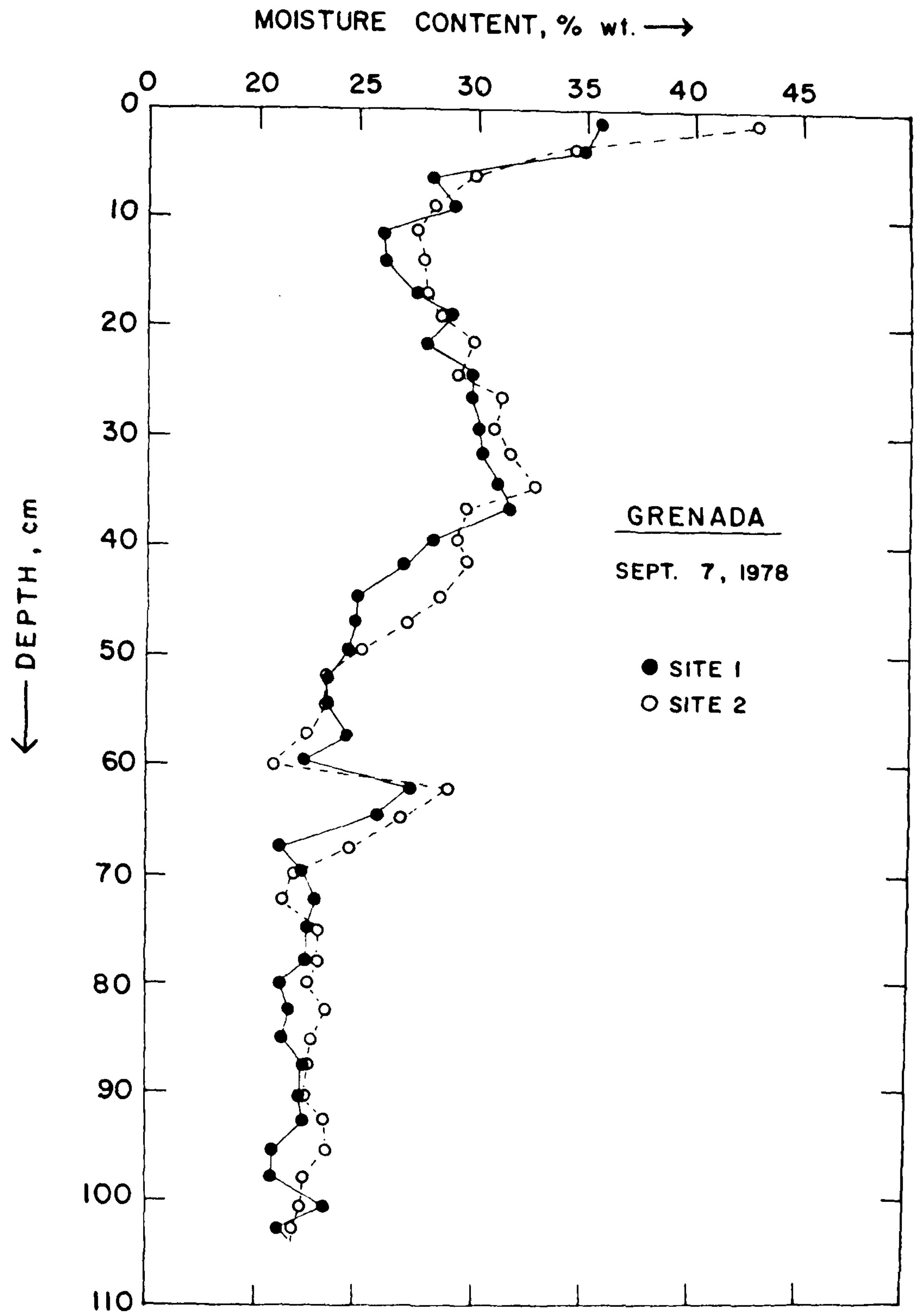
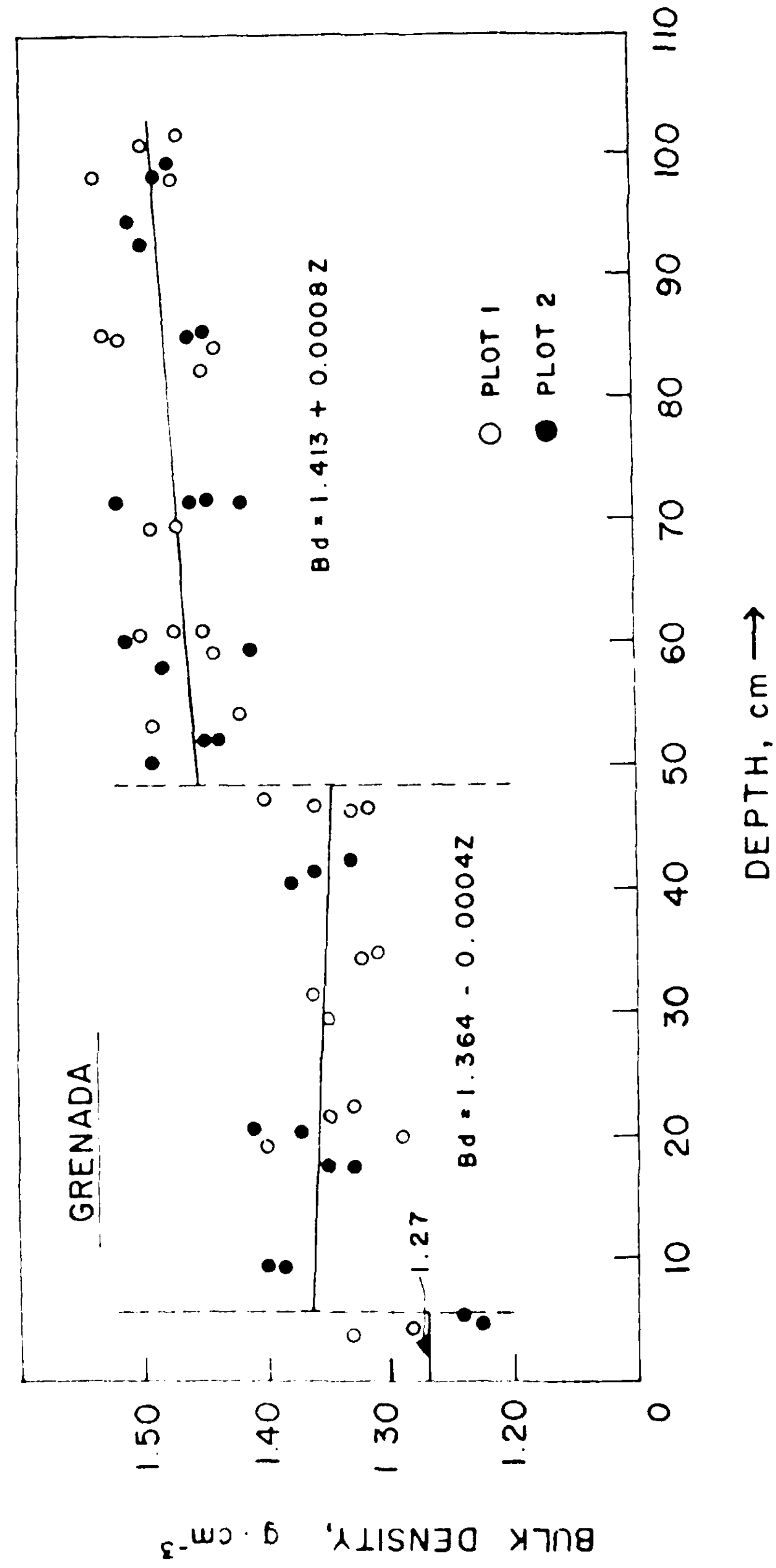


Figure 4 Gravimetric determinations of soil water content as a function of depth.


GRENADA
Bd = 1.364 - 0.00042Z
Bd = 1.413 + 0.0008Z
1.27
○ PLOT 1
● PLOT 2
DEPTH, cm →
BULK DENSITY, g · cm⁻³
1.50
1.40
1.30
1.20
0
10
20
30
40
50
60
70
80
90
100
110

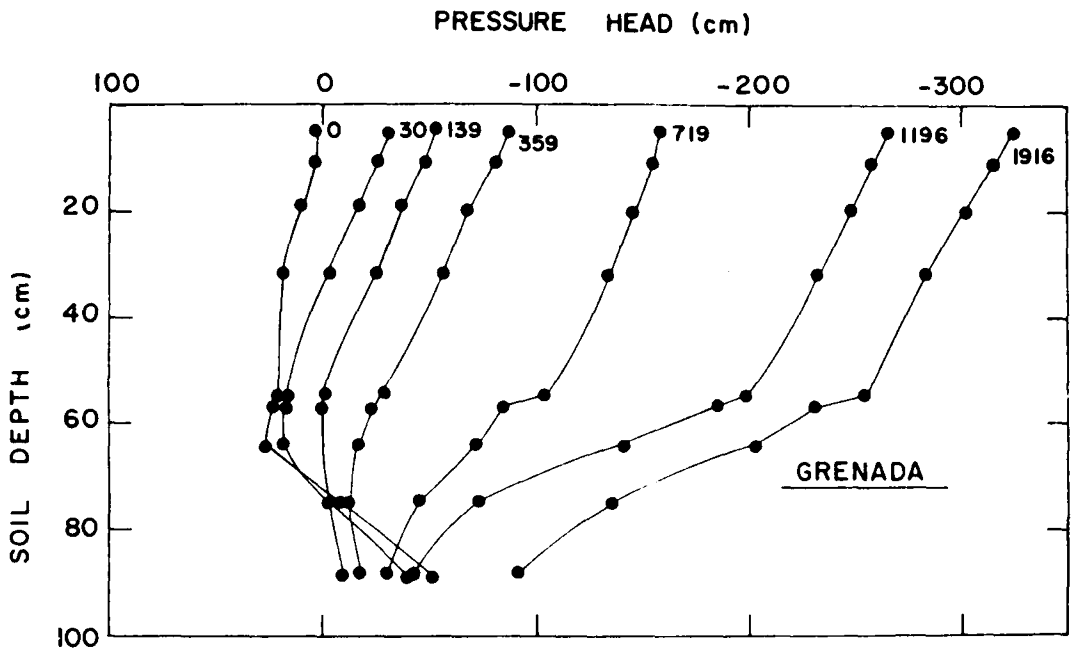


Figure 6 Pressure head relationships for a Grenada soil at different sampling times following ponding.

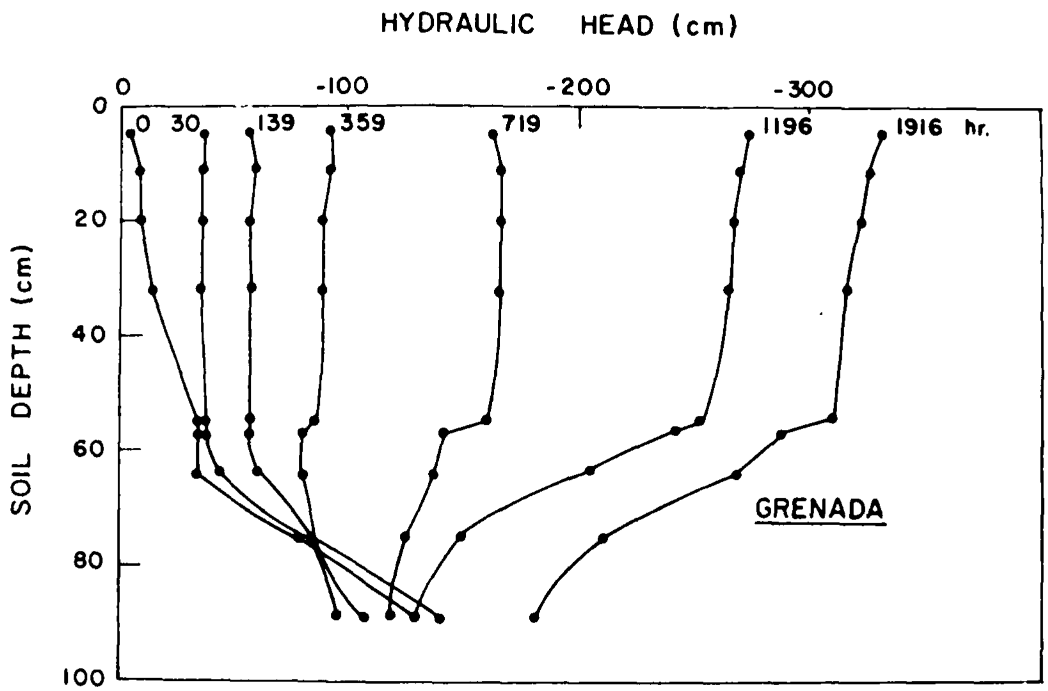


Figure 7 Hydraulic head relationships for a Grenada soil at different sampling times following ponding.

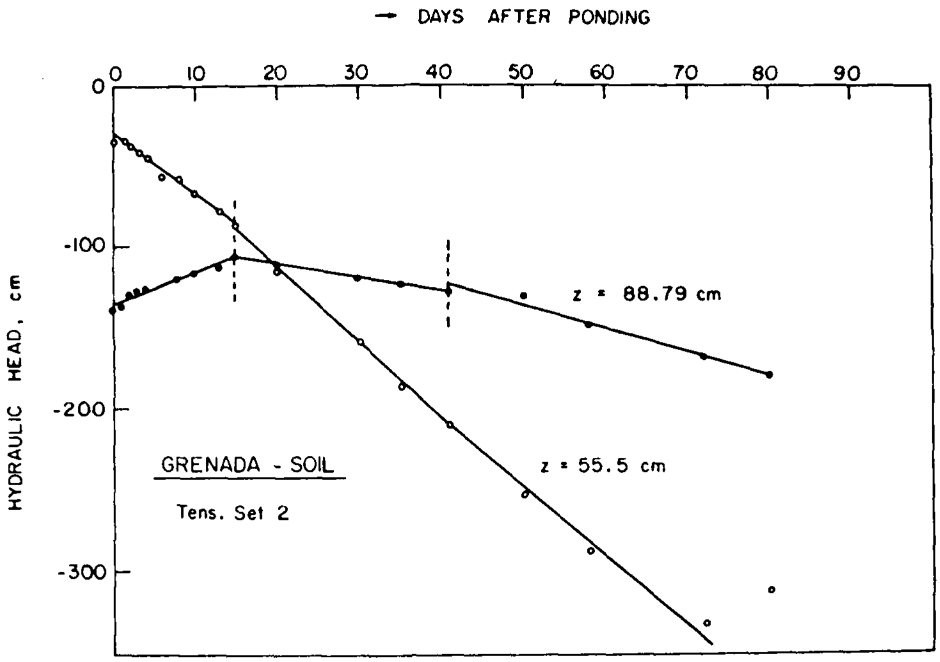


Figure 8 Observed and predicted hydraulic head at two tensiometer positions for a Grenada soil.

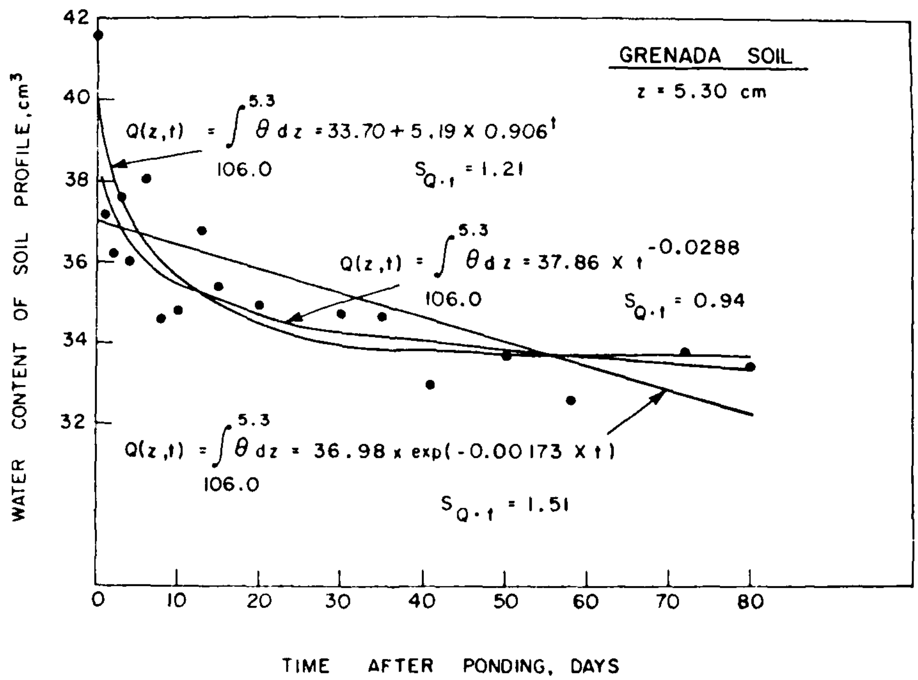


Figure 9 Observed and predicted water content of a Grenada soil profile.

tensiometers coupled with smoothing of data is a necessity to discerning direction of water movement. Table 1 indicates the frequency with which the various measurements were made. An example of smoothing tensiometer data is given in Fig. 8, where, for two tensiometers, the measured data were fitted to linear and power functions using a segmentation procedure. The gradual shift from a drainage to an evaporation profile can be explained by experimental conditions. The water-repellent building insulation material which was spread on the soil surface, apparently had a limited affinity for water notwithstanding the manufacturer's claims to the contrary. The net effect was for soil water to be gradually drawn into this material. Some of this water was subsequently lost by evaporation to the atmosphere through holes in the plastic sheets which developed over time. Evaporation sustained water movement out of the profile. A second consequence was, the presence of a near vertical or constant hydraulic head in the soil region above the pan rather than the customary large gradients which usually are observed when a soil surface is exposed to the atmosphere.

This experimental effect ultimately yielded an *evaporation profile* instead of a drainage profile. However, it was a blessing in disguise, for computing hydraulic conductivities, in that water desorption took place over a finite moisture content range in the soil surface. This would not have been possible if a zero-flux boundary had been maintained at the soil surface of the Grenada site.

The apparent non-conducting characteristic of the pan region permitted the establishment of a zero flux boundary layer at some distance into the soil profile. The change in the integrated water content of the soil profile taken from the zero-flux plane up to a depth of 5.3 cm, as indicated by equation (6), is shown in Fig. 9. Various functions were fitted to the measured integrated moisture content values, each based on two samplings taken at random locations in the plot. The power function yielded the smallest value of the standard error of the estimate. This was true for nearly all regressions on the integrated water content values, $Q(z,t)$.

The predicted $Q(z,t)$ relationship enabled computations of hydraulic conductivity as a function of moisture content for the various soil horizons. Figures 10 thru 14 show these relationships for the respective horizons of the Grenada soil. The data were regressed on an exponential

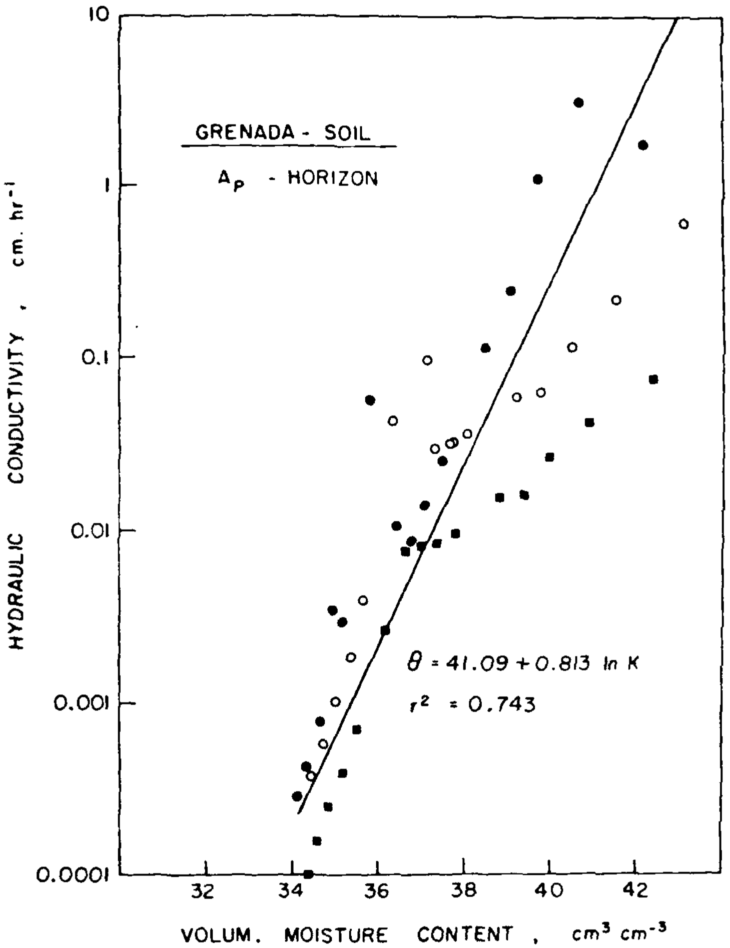


Figure 10 In situ hydraulic conductivity vs volumetric water content for the Ap-horizon of the Grenada soil.

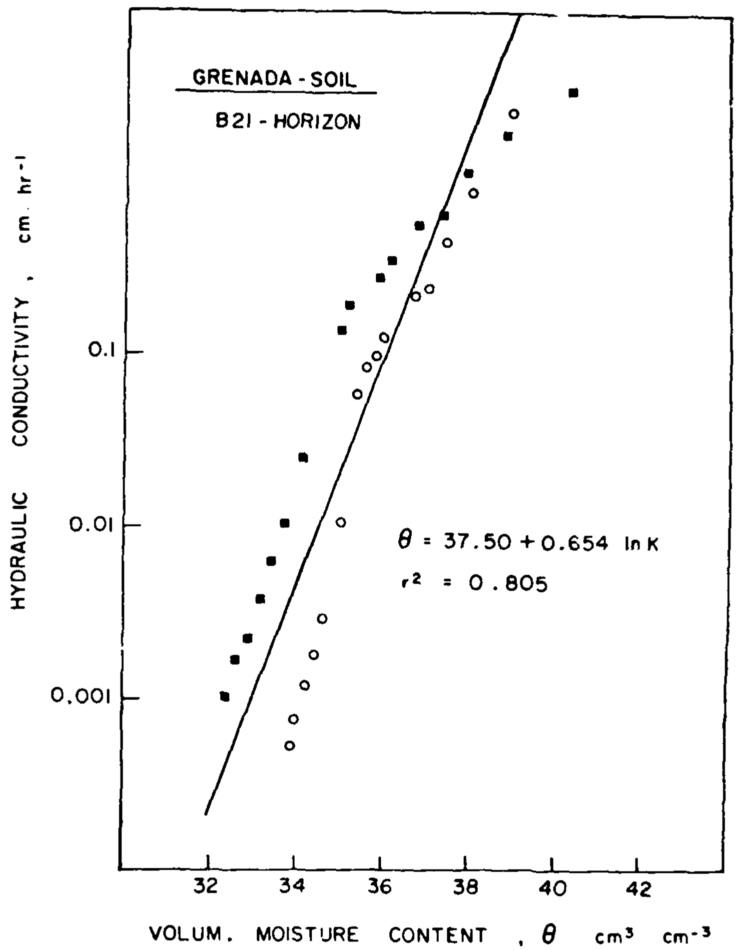


Figure 11 In situ hydraulic conductivity vs volumetric water content for the B21-horizon of the Grenada soil.

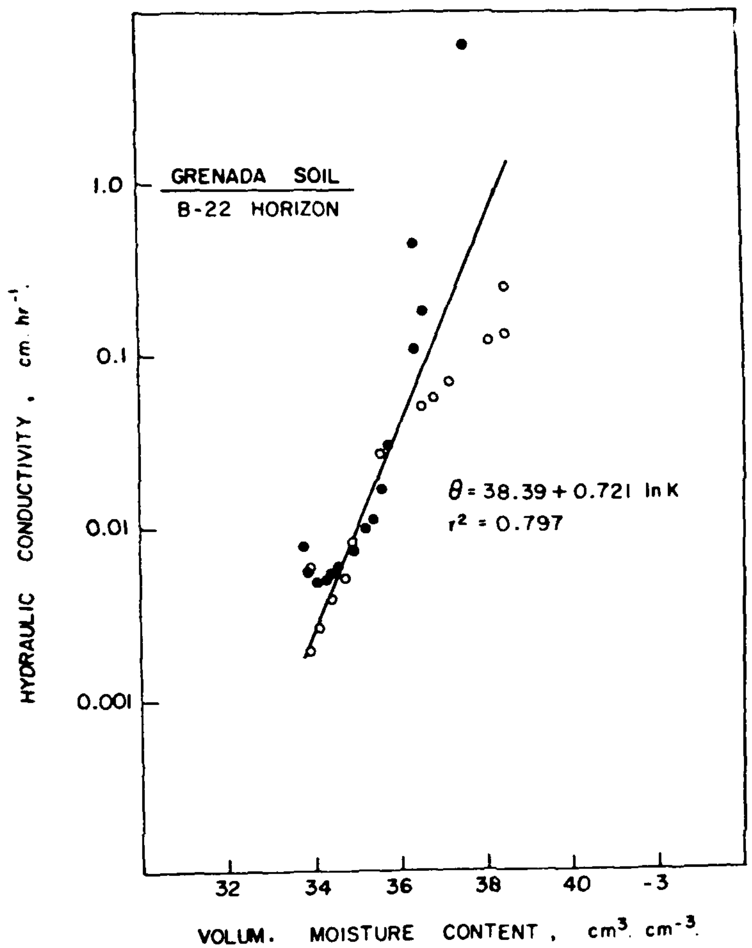


Figure 12 *In situ* hydraulic conductivity *vs* volumetric water content for the B22-horizon of the Grenada soil.

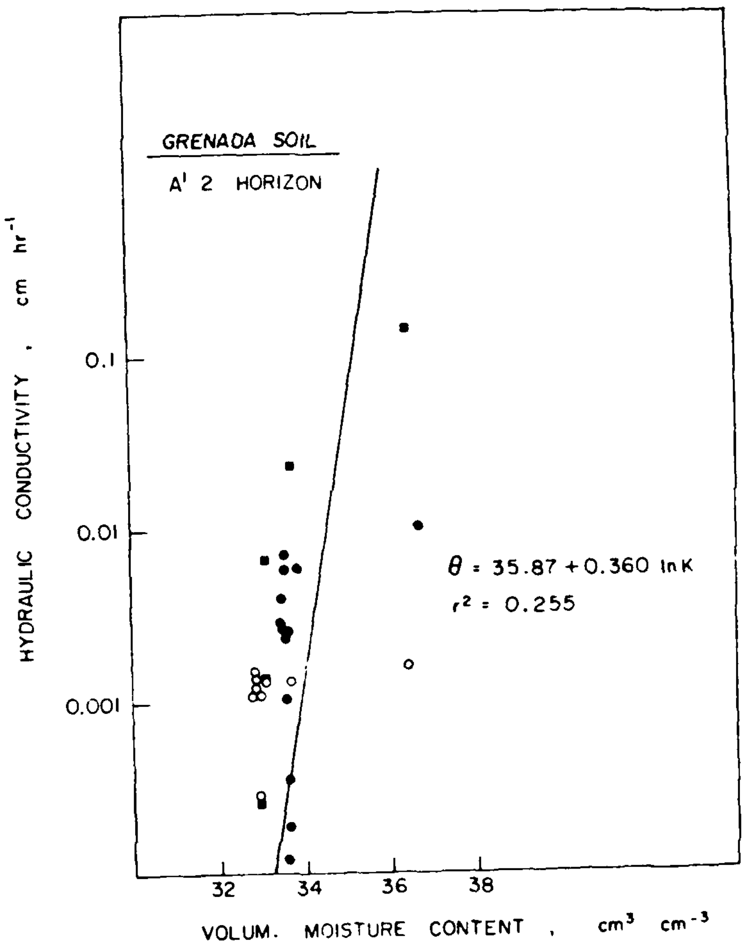


Figure 13 *In situ* hydraulic conductivity *vs* volumetric water content for the A'2-horizon of the Grenada soil.

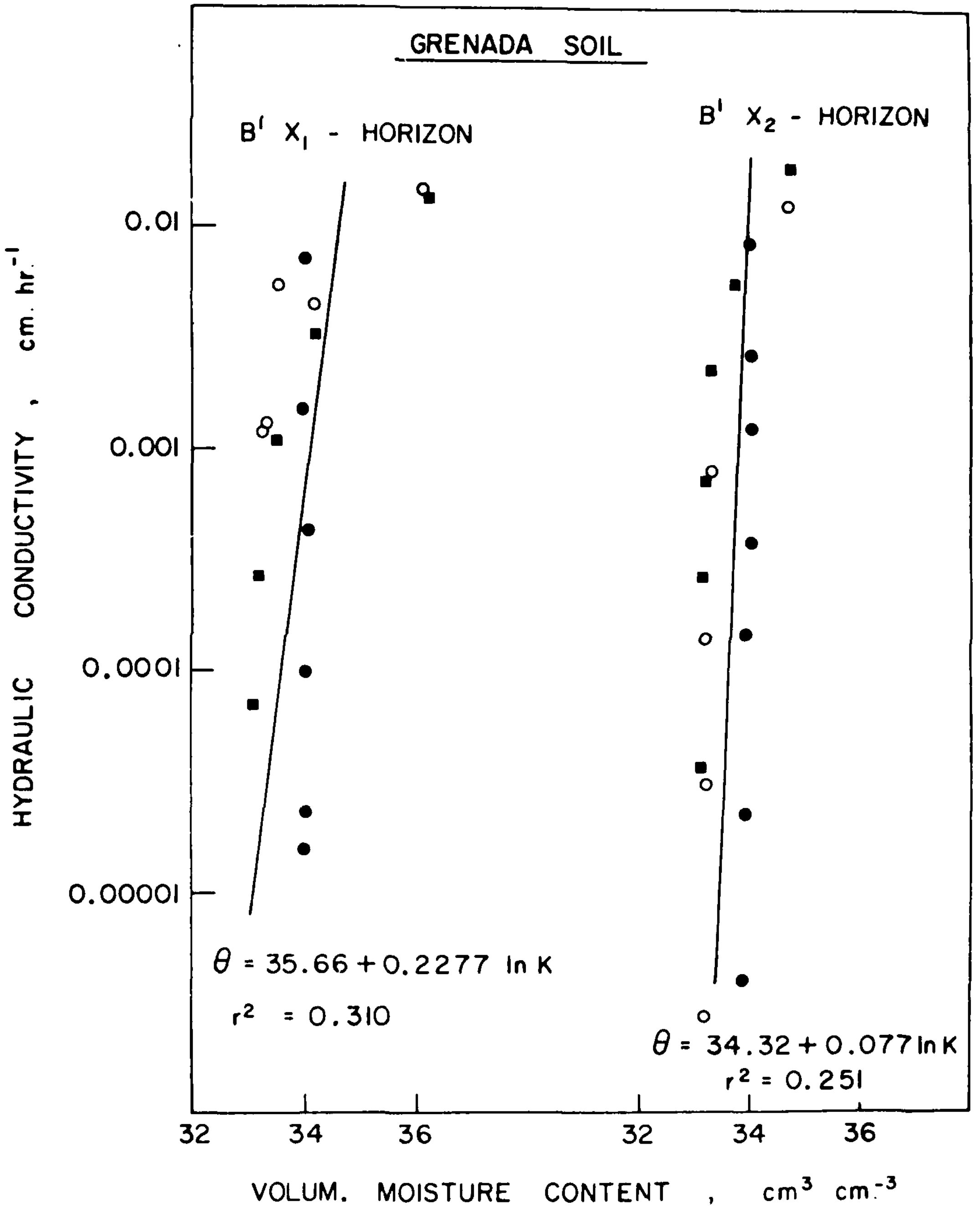


Figure 14 *In situ* hydraulic conductivity *vs* volumetric water content for the B'X1 and B'X2 horizons of the Grenada soil.

function. The analysis indicate a rapid change in the hydraulic conductivity with change in moisture content. The rate of change was largest for the deepest soil horizon and decreased for horizons closer to the soil surface. However, the soil moisture content range for which the conductivities were computed was very small.

Fluxes to soil layers deeper than 106.0 cm were estimated according to the computed change in the predicted integrated water content of the soil profile for the pan region (106.0 m to 61.90 cm). When computed for the time span, when the pressure head values in the soil profile had positive values and assuming that the zero flux plane was located at the pan's upper boundary, an average percolation rate of 0.03 cm^3 of water per cm^2 of soil per day was obtained for a 7 day interval. This translates into a saturated hydraulic conductivity of about 0.1 cm/day.

2.3.2 Loring Site

Research activities involved three plots. One plot was studied under evaporation conditions, the second plot represented a drainage experiment, and the third plot involved first a drainage experiment followed - after rewetting - by an evaporation study. The bulk density - depth relationship for each plot is given in Fig. 15. All three plots were characterized by a slightly higher bulk density in the upper 8 to 20 cm of the soil profile. This increased bulk density was probably due to compaction by cattle traffic. The bulk density throughout the soil profile was relatively invariant although a slight increase was noted at about 100 cm of soil depth on plots 2 and 3. On the other hand, Plot 1 showed a significant increase at about 85 cm of soil depth. The increase presumably reflected the transition into the Roxane formation (Fig. 1). The impact of the Roxane formation on water movement in the Loring plots, however, was not as readily apparent as that on the Grenada plots.

The wetting phase on all plots was marred by the development of small cracks in the concrete lining due to a finite, but small swelling capacity of this soil. Free water seeped through these cracks into the trench. The same problem had been experienced on the Grenada plots. Infiltration measurements, therefore, were abandoned at some point into the run in favor of an intermittent wetting procedure to secure a wet profile for water movement under both drainage and evaporation conditions.

The drainage profiles of the Loring site (Plots 2 and 3) showed very similar responses. At the start of the observations (0 hrs), the pressure

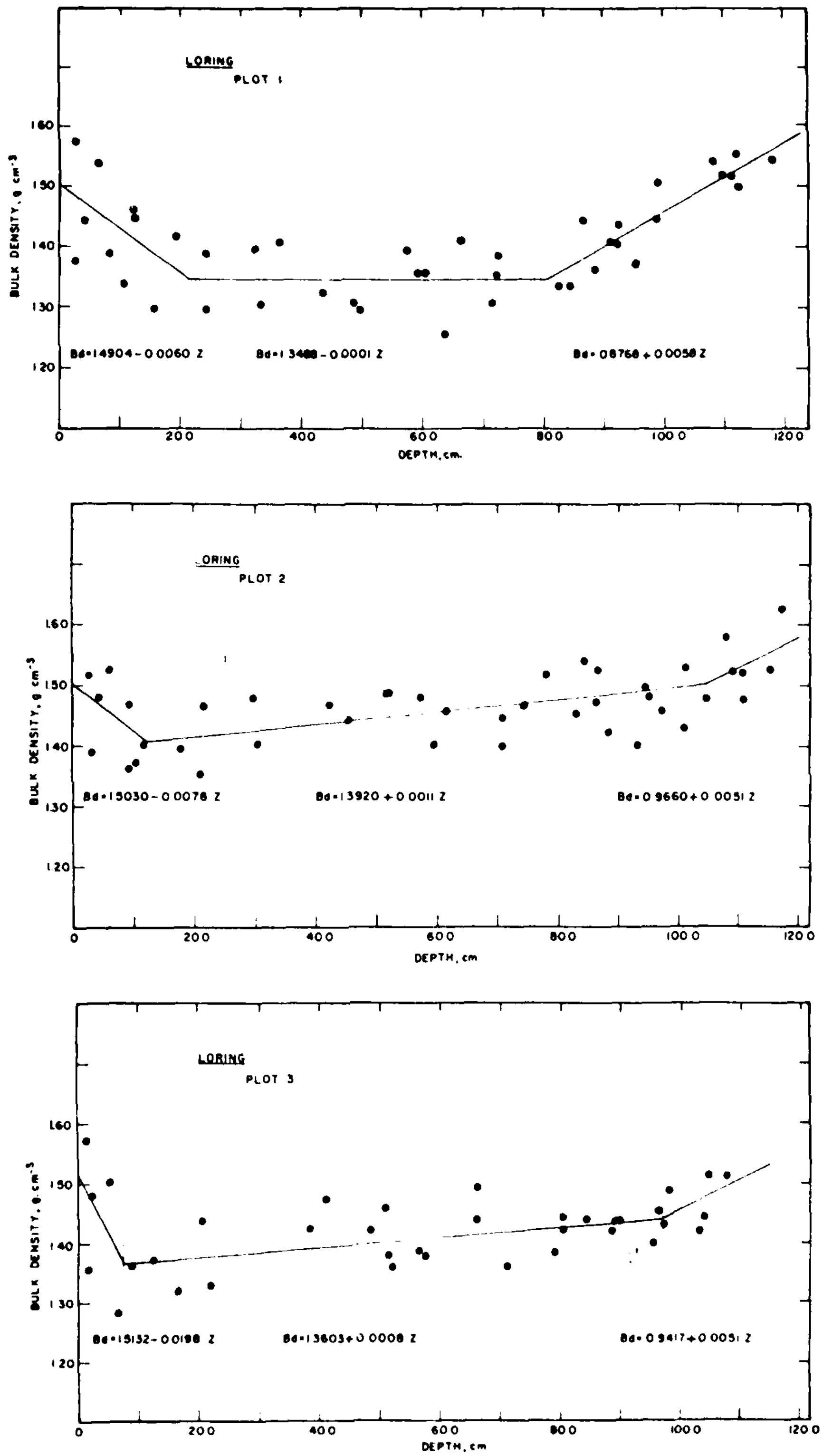
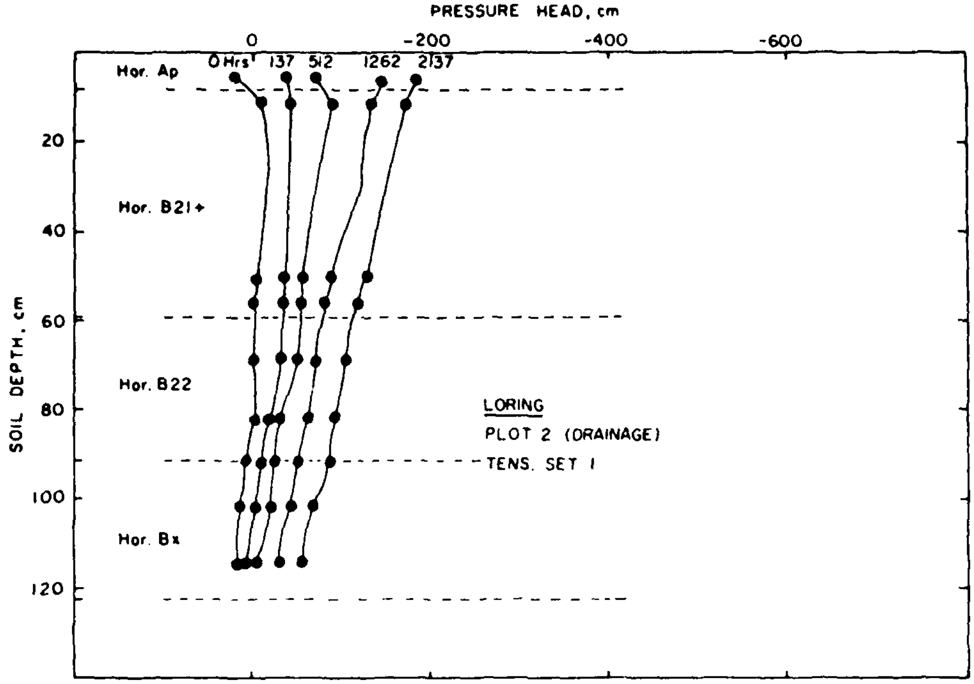


Figure 15 The bulk density - depth relationship for a Loring soil.

head beyond 80 cm of soil depth, Bx horizon, was positive and increased linearly (1:1 ratio) with depth on Plots 2 (Fig. 16) and 3 (Fig. 17), the 102-124 cm depth range of Plot 2 excepted. Also a linear increase in pressure head was observed from 7 to 53 cm for the B2 horizon of Plot 3 (Fig. 17). However, the pressure head covered both positive and negative values. In accordance with a one on one increase in pressure head with depth, the concomittant hydraulic head should be about constant. This conclusion is confirmed upon examining Fig. 17. A small drainage gradient however, is noted at the bottom end of this profile.

Pressure heads and hydraulic heads on plot 3 decreased with time. However, the decreases were at extremely slow rates. After 1028 hours, only a shift of about 55 cm of water pressure was measured in the Bx horizon, which suggests poor internal drainage or/and the presence of a flow restrictive layer deeper in the soil profile. Also, the fraction of soil water that is held at pressures in excess of 0 cm, moved laterally and dissipated into the trenches surrounding the plot. The frequent samplings, requiring plot surface exposure to the atmosphere, led to a slight water loss by evaporation in the upper 6 to 7 cm of the plot. On the other hand, the hydraulic gradients in the horizons below this layer indicated appreciable drainage gradients.

Plot 2 responded in a manner similar to that of Plot 3. A positive pressure head was noted in the BX horizon (85-152 cm), which slowly dissipated with time. Wetting of this plot was less prolonged than on the other plots. This may in part account for the initially smaller values of hydraulic and pressure heads. Secondly, this profile showed up to 512 hrs after wetting a draining gradient throughout the soil profile. At 1262 hrs following wetting, a reversal in the gradient was noted in the upper part of the soil profile with the zero-flux plane located somewhere between 12 and 56 cm of soil depth. At 2137 hrs, the zero-flux plane had moved down to about 80 cm of soil depths. However, the near equilibrium values of the hydraulic head indicate that little water movement took place in either direction. The upward or evaporation flux was mainly caused by the repeated plot exposure during gravimetric sampling. This conclusion is also corroborated by the relatively large gradients in the 0 to 12 cm soil layer.



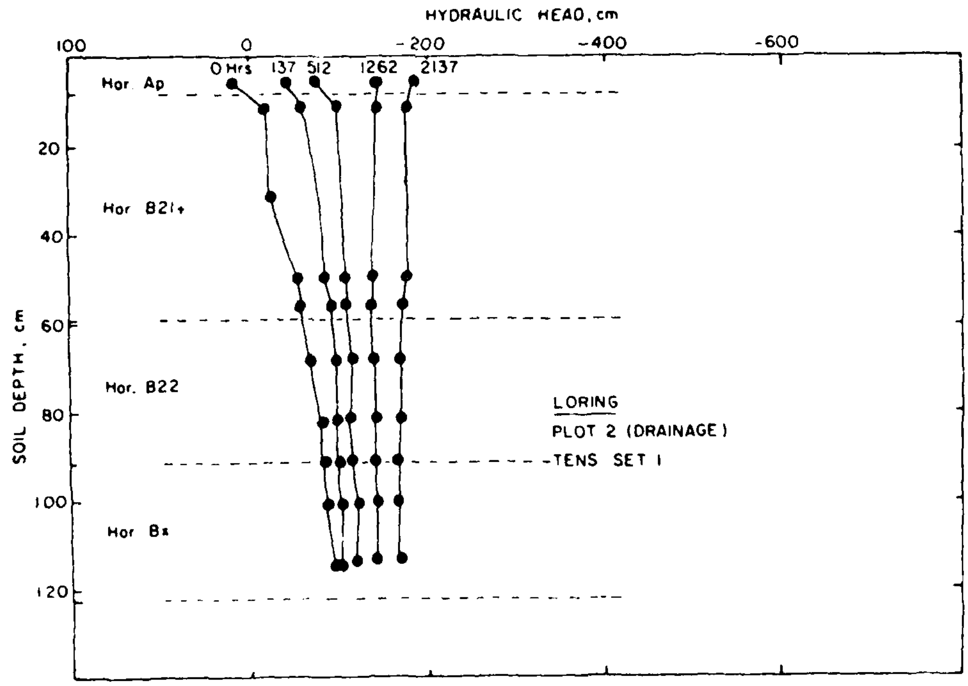


Figure 16 Pressure head and hydraulic head relationships during drainage for a Loring soil (Plot 2).

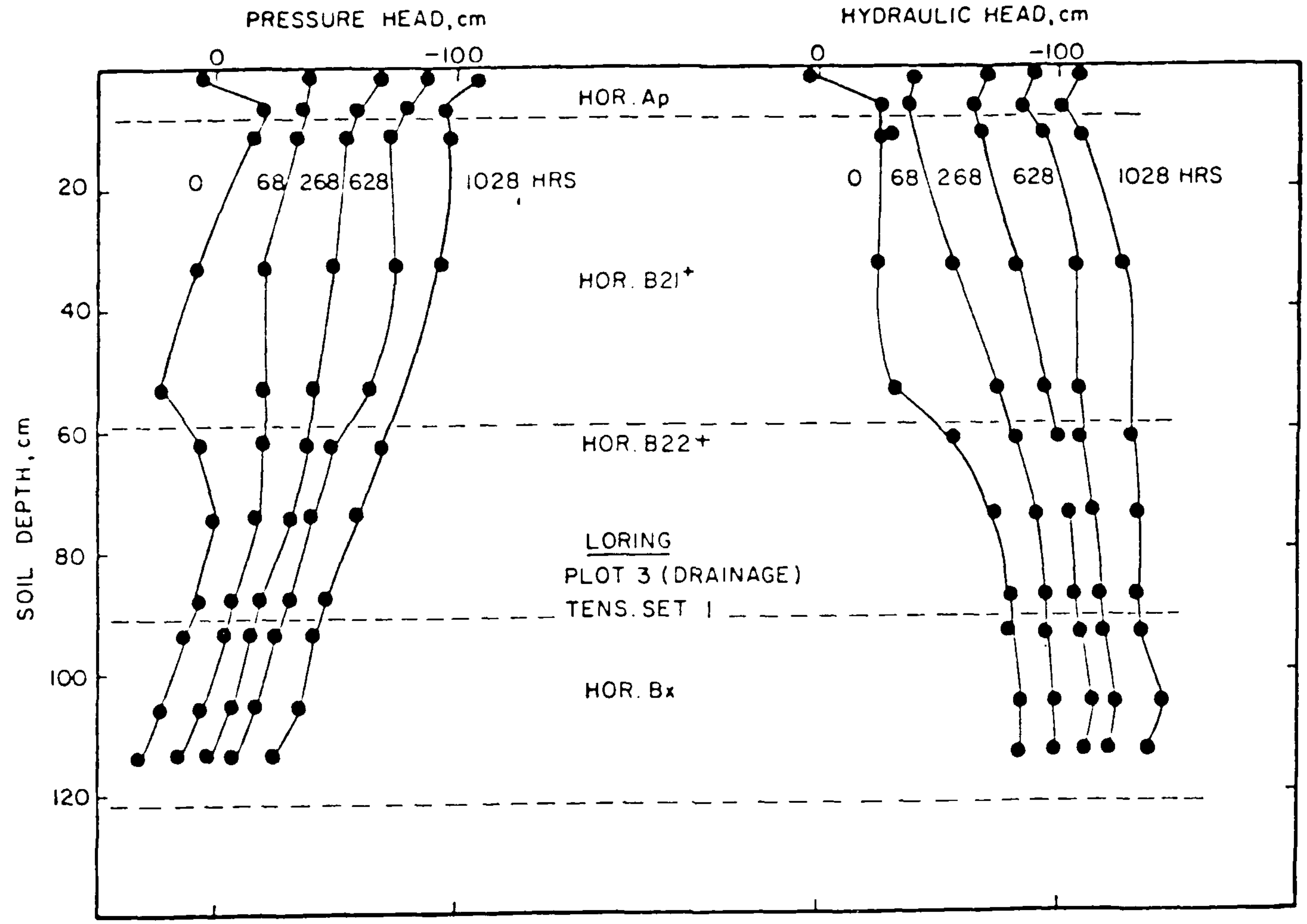


Figure 17 Pressure head and hydraulic head relationships during drainage for a Loring soil (Plot 3).

Large evaporation gradients are noted when the soils are directly exposed to the atmosphere (Plots 1 and 3 evap.), although direct sunlight exposure was avoided. The hydraulic and pressure head relations (Figs. 18 and 19) show, however, a distinct difference with those obtained for the Grenada plots. The greater uniformity in pressure and hydraulic data of the latter plots is a consequence of the manner in which the plot surface was protected on that site as has been explained elsewhere. Drying of the directly exposed soil surface has a "self-sealing" effect on moisture movement. Although the effect of evaporation on hydraulic head was ultimately felt throughout the soil profile, the amount of moisture loss, as dictated by the combined effect of conductivity and gradient, was mainly concentrated in the top 20 cm.

The allocation of soil water loss to drainage and evaporation processes requires a definition of the zero flux plane as a function of time. As estimate of the depth-time relationship based on a power function fit of estimated maxima of hydraulic heads at various sampling dates yielded for Plot 3 the following relationship:

$$d = 0.046\ t^{0.99} \tag{12}$$

where d is depth and t is time. No attempt was made to arrive at a similar relationship for Plot 1.

Flux computations based on a preliminary numerical analysis, along lines of equation (7), indicate measurable evaporative losses as may be concluded from the decrease of the average moisture content per unit volume in the evaporation zone (Fig. 20). On the other hand, drainage losses to deeper soil layers could not be detected. In fact, the regression curve fitted to gravimetrically based water content data of the drainage zone of Plot 3 suggested a small increase in the average water content. Also, it should be noted that 1.20 m deep standpipes, placed at various locations in the plot and filled with water at the beginning of the experiment did not show a measurable water loss for the duration of the experiment (≅ 1000 hrs). On the other hand, integrated water content computations based on gravimentric data for both Plots 2 and 3 indicated marginal drainage losses. They are estimated to be 0.6 and 1.9 cm^3 per cm^2 of soil surface per 1000 hrs for Plots 2 and 3 respectively (Fig. 21). The magnitude of

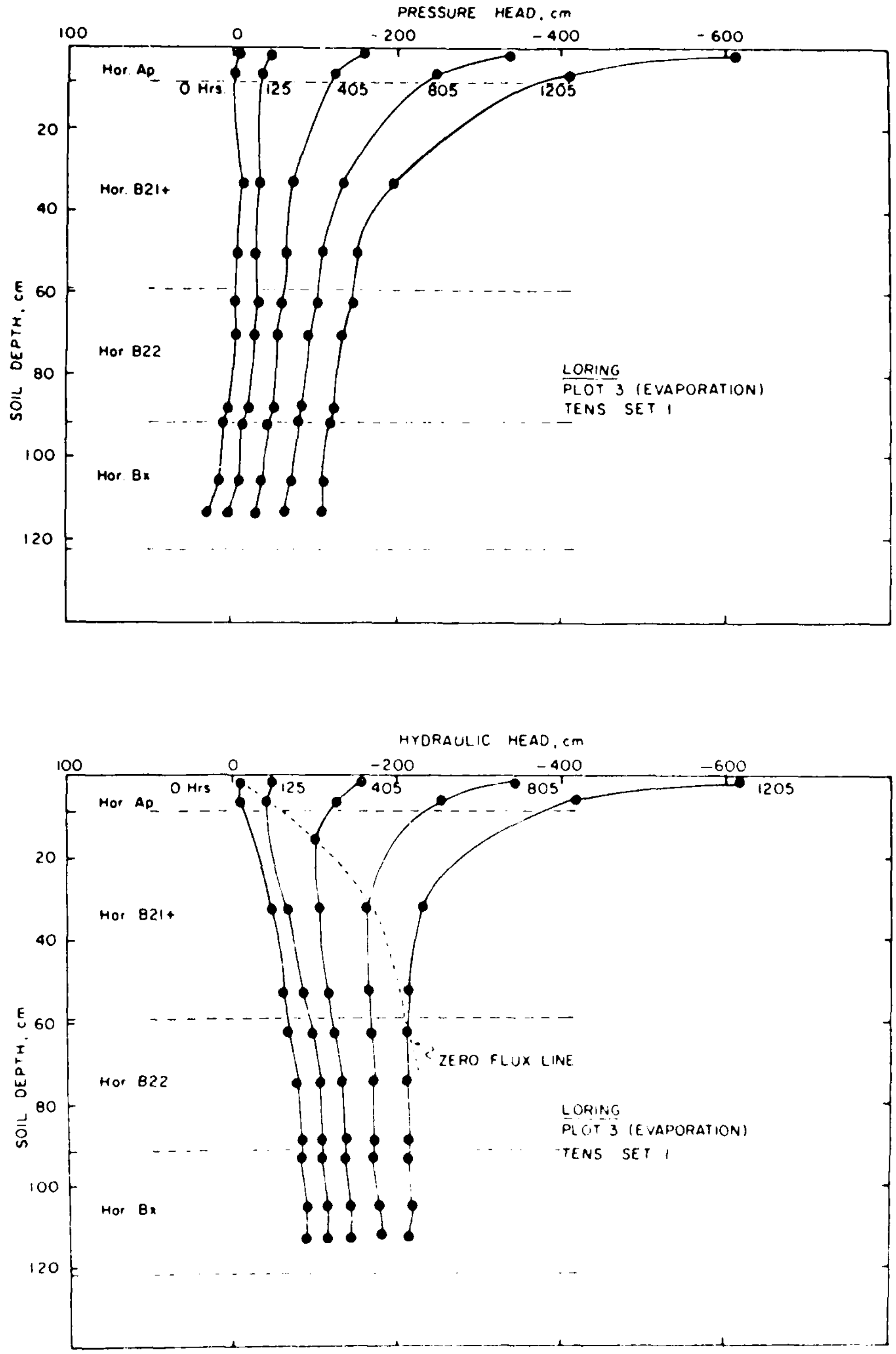
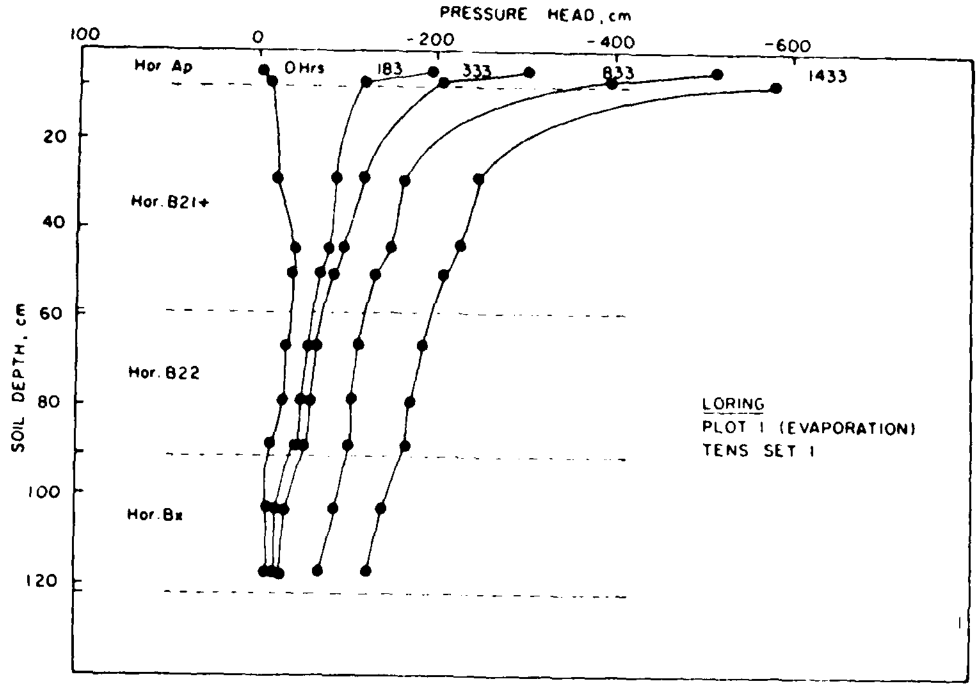


Figure 18 Pressure head and hydraulic head relationships during simultaneous evaporation and drainage for a Loring soil (Plot 3).



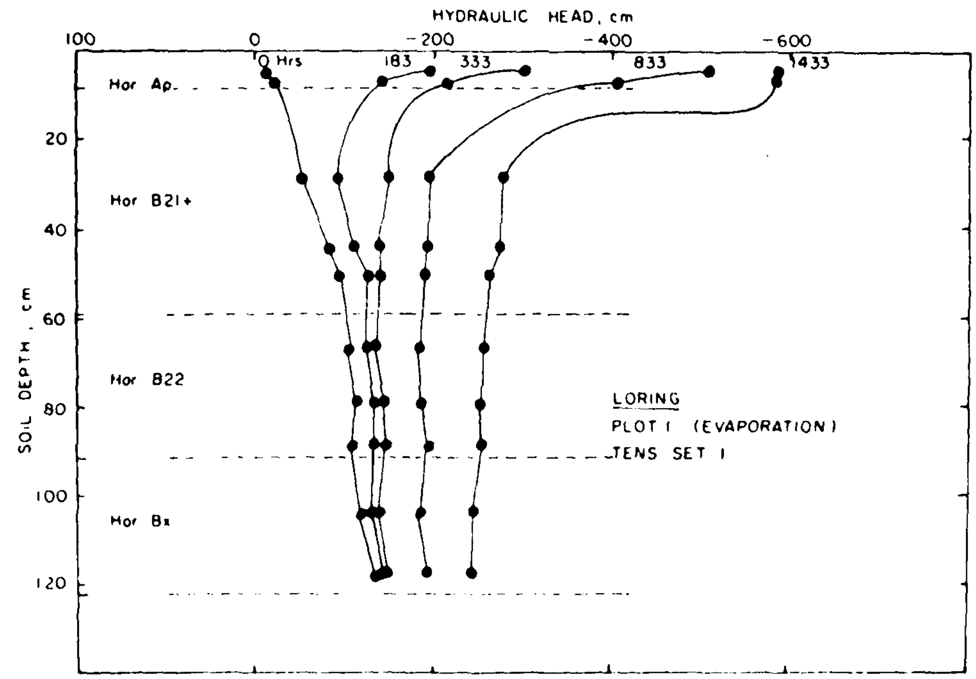


Figure 19 Pressure head and hydraulic head relationships during simil-taneous evaporation and drainage for a Loring soil (Plot 1).

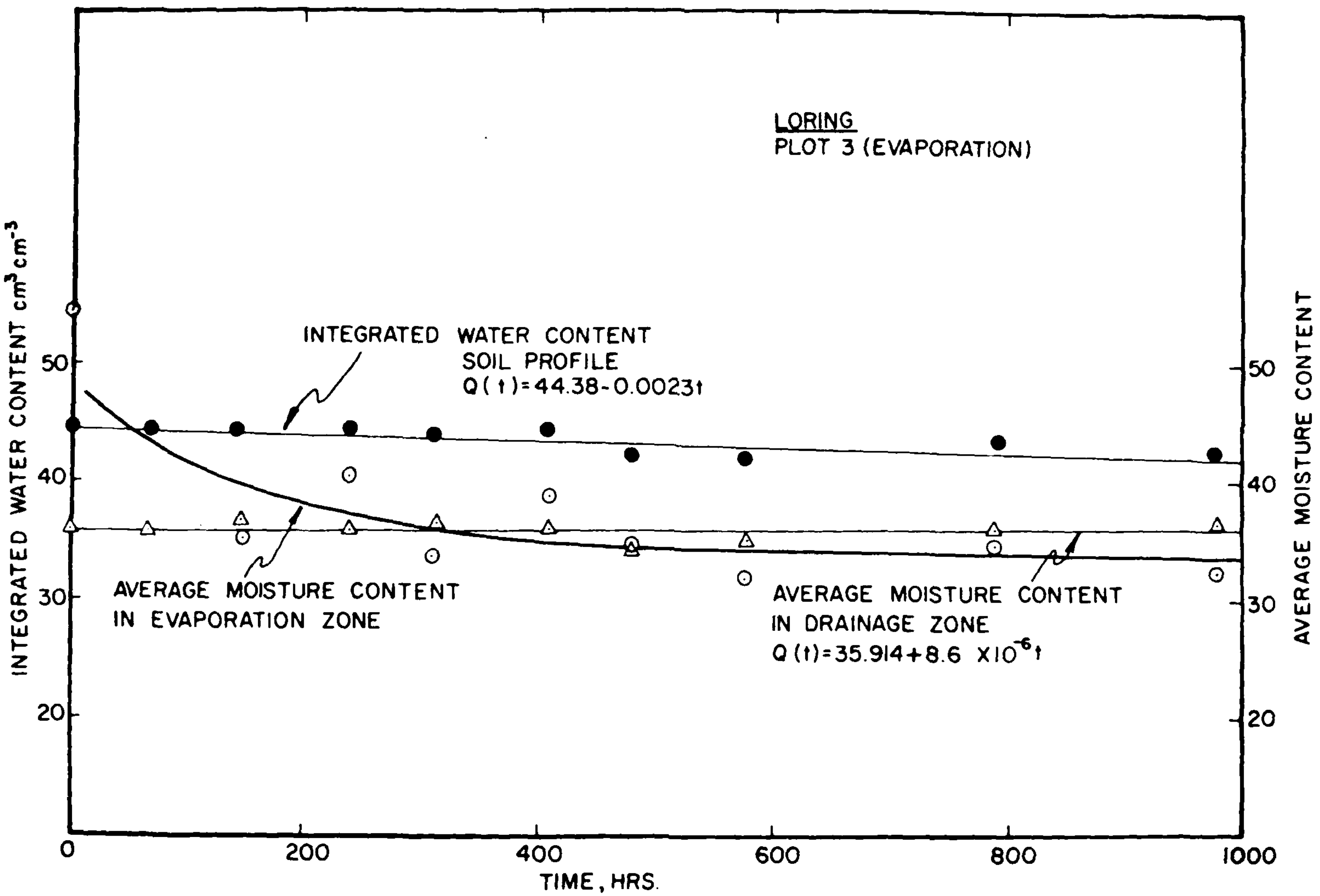


Figure 20 Integrated and average volumetric water content relationships for a Loring soil (Plot 3).

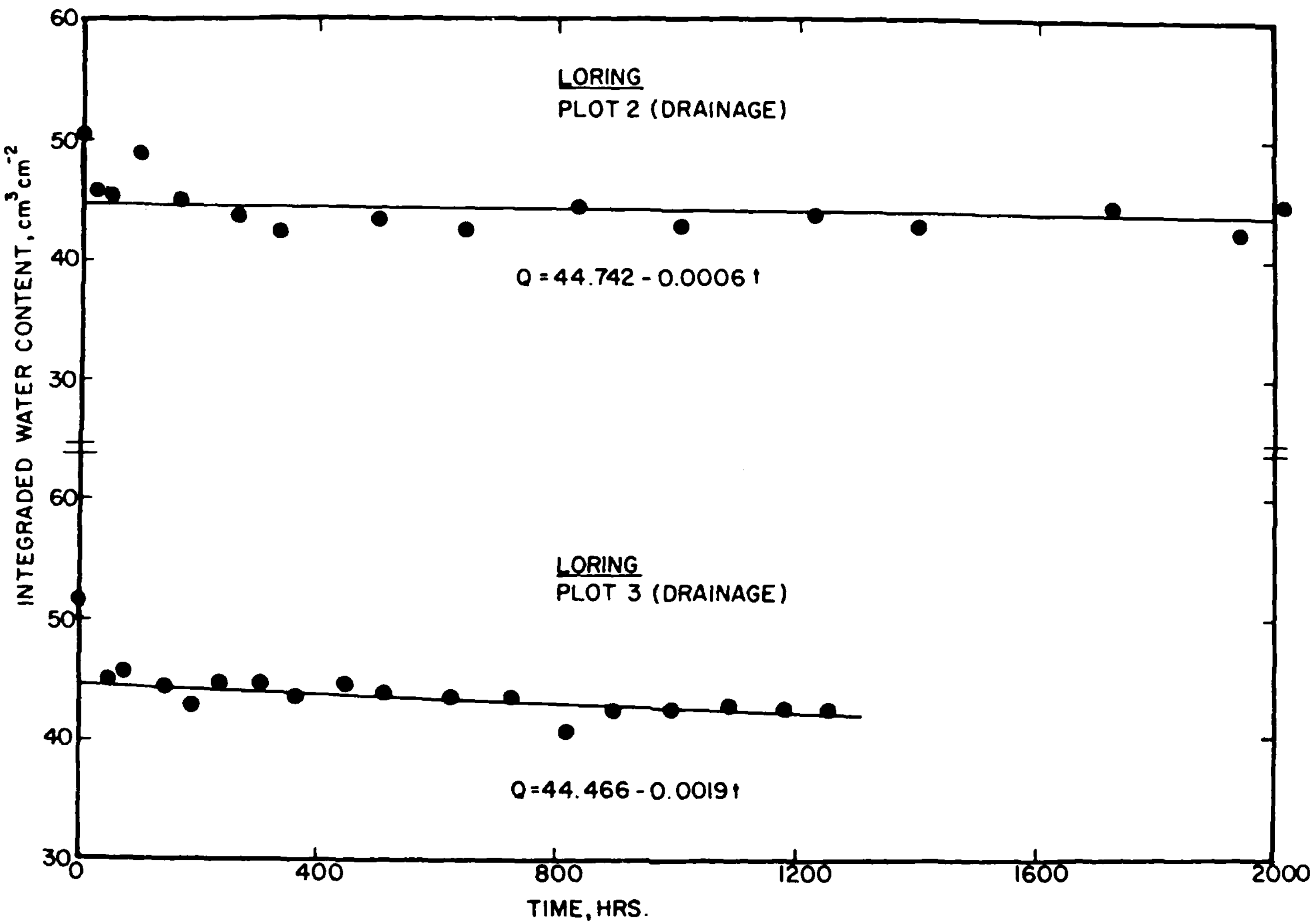


Figure 21 The integrated water content-time relationship for a Loring soil under drainage conditions.

these losses suggest that deep percolation for all practical purposes is nonexistent on this soil. Most infiltrated water of this profile will be lost either by evapotranspirational demand of vegetation or by lateral or interflow processes.

2.3.3 Memphis Site

Hydraulic measurements on this site involved two plots; one plot was studied under drainage conditions and a second plot under evaporation conditions. The bulk density relationships for both plots, shown in Fig. 22, indicate excellent agreement between plots. Fig. 22 also indicates good agreement with bulk density values of the "above the pan" part of the Loring and Grenada soil profile. Also traffic compaction was noticeable. However, there was no evidence of a different stratigraphic formation within the profile depth that was investigated.

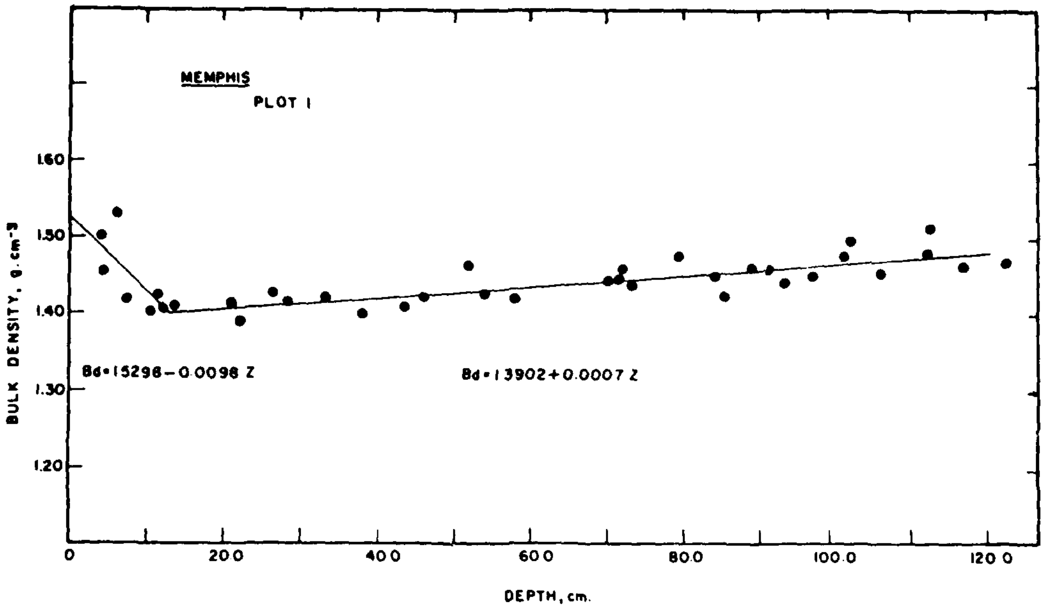
Pressure head relationships indicated a near saturated condition throughout the profile at the commencement of the experiment (Figs. 23 and 24) with positive pressures at most points in the soil profile for Plot 1 and near zero pressures on Plot 2. Internal drainage was allowed to proceed for a few days on Plot 2 before data were taken.

Pressure head relationships on both plots assumed initially an appro‚ ːate vertical slope, which changed with the passage of time towards a negative slope in the bottom end of the profile (Figs. 23 and 24). These slopes are indicative of strong drainage gradients. This may also be concluded from the hydraulic head relationships.

Hydraulic gradients in the drainage plot appear to be largest in the B3t horizon, while the smallest gradients were observed in the A_p horizon of plot 1. The hydraulic head decreased more rapidly in the deeper part of the soil profile (140 cm of water pressure at 120 cm soil depth vs. 110 cm of water pressure at 20 cm of soil depth) than closer to the soil surface.

The evaporation plot had similar drainage characteristics in the lower part of the soil profile as the drainage plot. However, the upper part of the profile was strongly affected by evaporation fluxes (Fig. 24). The zero-flux plane-depth relationship was not estimated.

The drainage flux out of the 122 cm thick soil profile was estimated from the integrated soil water content versus time relationship of Plot 1 (Fig. 25). Computations, based on a straight line fit to the gravimetrically determined water content data, show a drainage loss of 1.1 cm^3 per 1 cm^2 of surface area for a 122 cm thick soil profile during a 1000



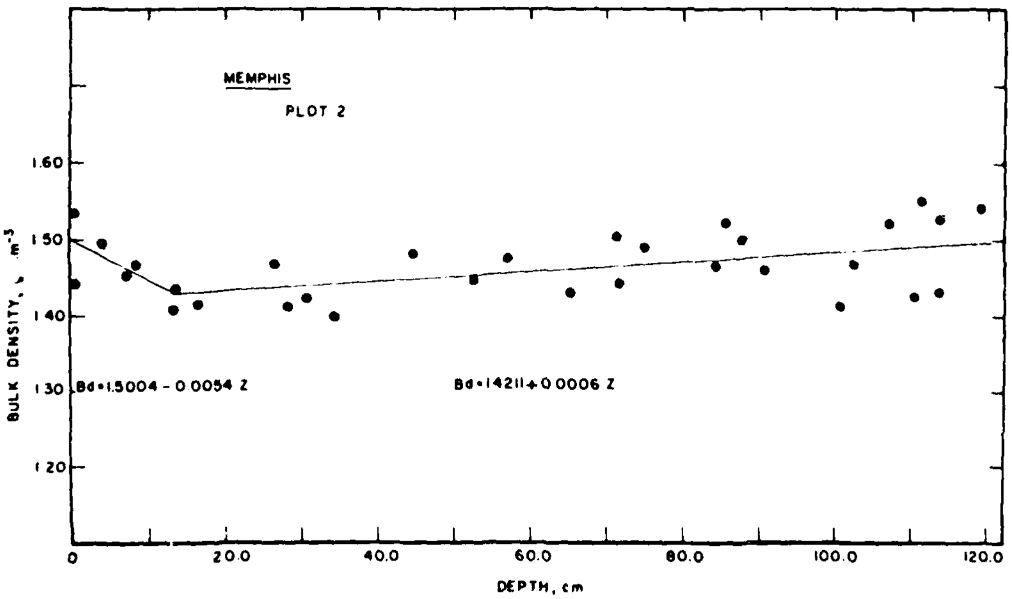


Figure 22 The bulk density - depth relationship for a Memphis soil.

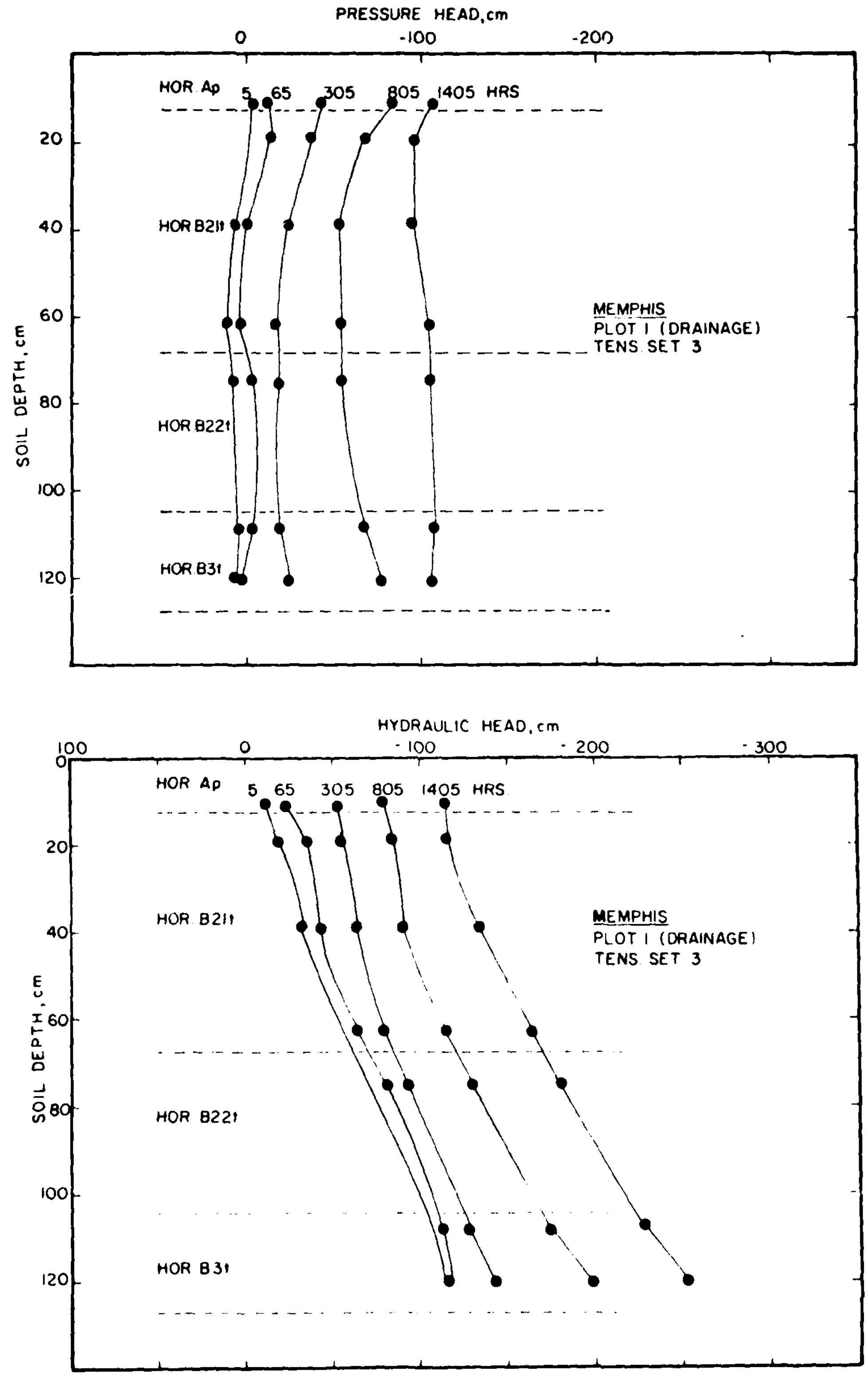


Figure 23 Pressure head and hydraulic head relationships during drainage for a Memphis soil.

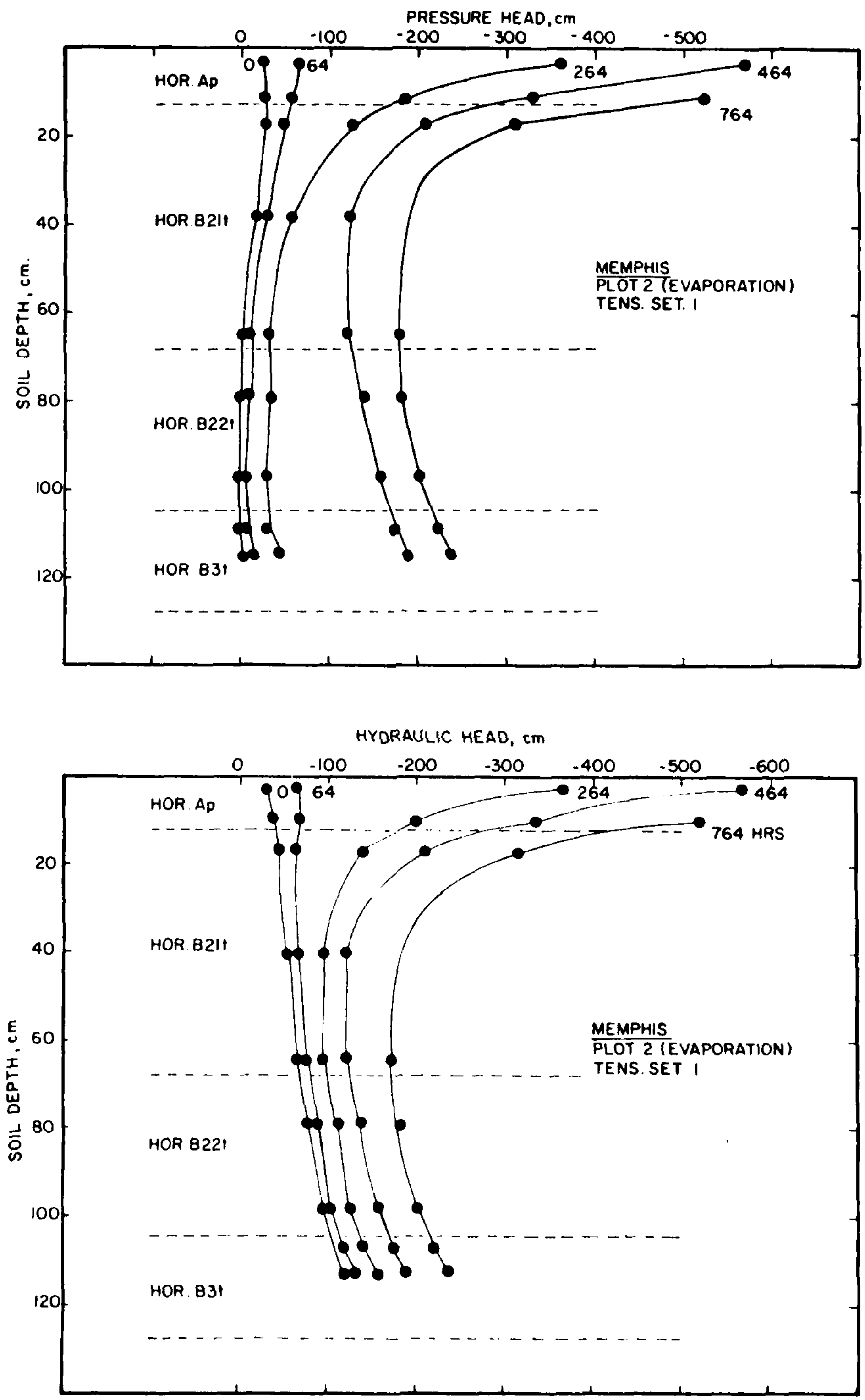
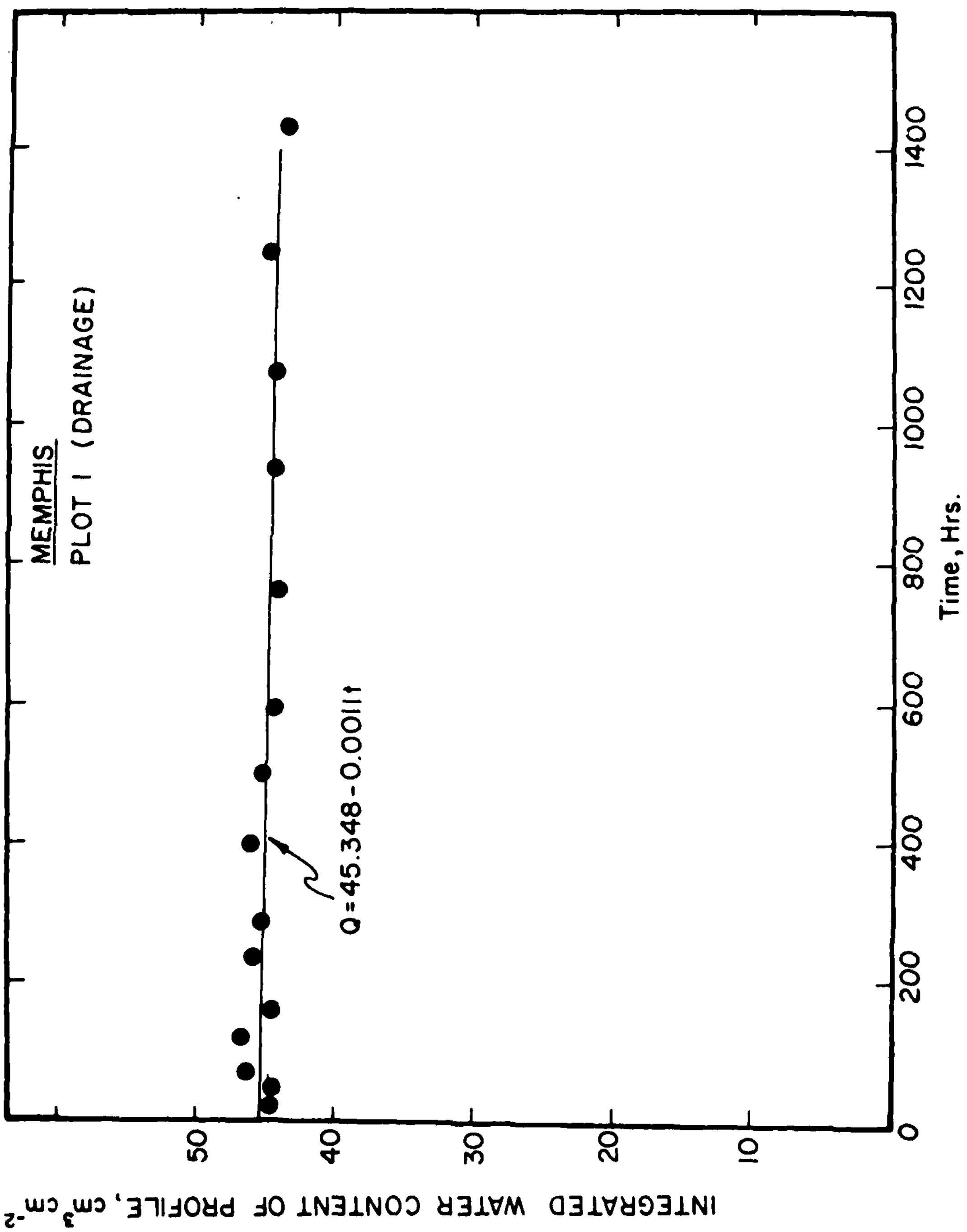


Figure 24 Pressure head and hydraulic head relationships during simultaneous drainage and evaporation for a Memphis soil.


MEMPHIS
PLOT 1 (DRAINAGE)
Q=45.348-0.0011t
Time, Hrs.
0
200
400
600
800
1000
1200
1400
INTEGRATED WATER CONTENT OF PROFILE, cm3cm-2
10
20
30
40
50

hour period. This loss represents only 2.4% of the total water content of the profile. Therefore, the amount of water percolating to deeper soil horizons through matrix moisture movement may be considered small.

2.3.4 Vicksburg Site

Hydraulic characterization of this site involved three plots, all of which were studied under drainage conditions. The plots were located in close proximity to each other. Nevertheless, the soil was much less homogeneous as compared to Memphis and Loring profiles and soil horizons were not always located at the same position in the profile. The horizons indicated on Figures 27, 28 and 29 are those identified individually for each plot by the SCS district soil scientist. The bulk density relationship (Fig. 26) used for converting the gravimentric moisture content value to volumetric units, therefore, was based on the joint data for all plots. Several observations can be made. First, the bulk density increases with depth in the plow layer. A relatively short stretch of the soil profile is characterized by a near constant value of the bulk density. This part of the profile represents a plow pan, which appears to have slightly larger bulk density values and has definite layers resulting from cultivation activities. The deeper part of the soil profile has a fairly constant bulk density which gradually increases with depth. However, data scatter is very much in evidence and may be attributed to the alluvial origin of this soil.

All plots show rapid draining characteristics. Drainage appears to be rather uniform over the entire soil profile as one might infer from the parallel shift of pressure head and hydraulic head relationships (Figs. 27 thru 29). Abrupt changes in gradients were observed on Plot 1 between horizons C3 and C4. The textural composition of these horizons (Table 2) indicate an abrupt shift towards a finer texture in horizon C4. The effect of the C4 horizon is to slow down the drainage process in the overburden. Also, a large hydraulic gradient was observed in the Ap horizon of plot 3 (Fig. 29). The net effect has been to commence the drainage experiment under partially desaturated conditions in the C1, C2, C3, and C4 horizons. The smoothest hydraulic response was obtained on Plot 2 (Fig. 28) where hydraulic gradients were similar throughout the profile.

Water fluxes to deeper parts of the soil profile were estimated from the integrated water content *versus* depth relationship by fitting the

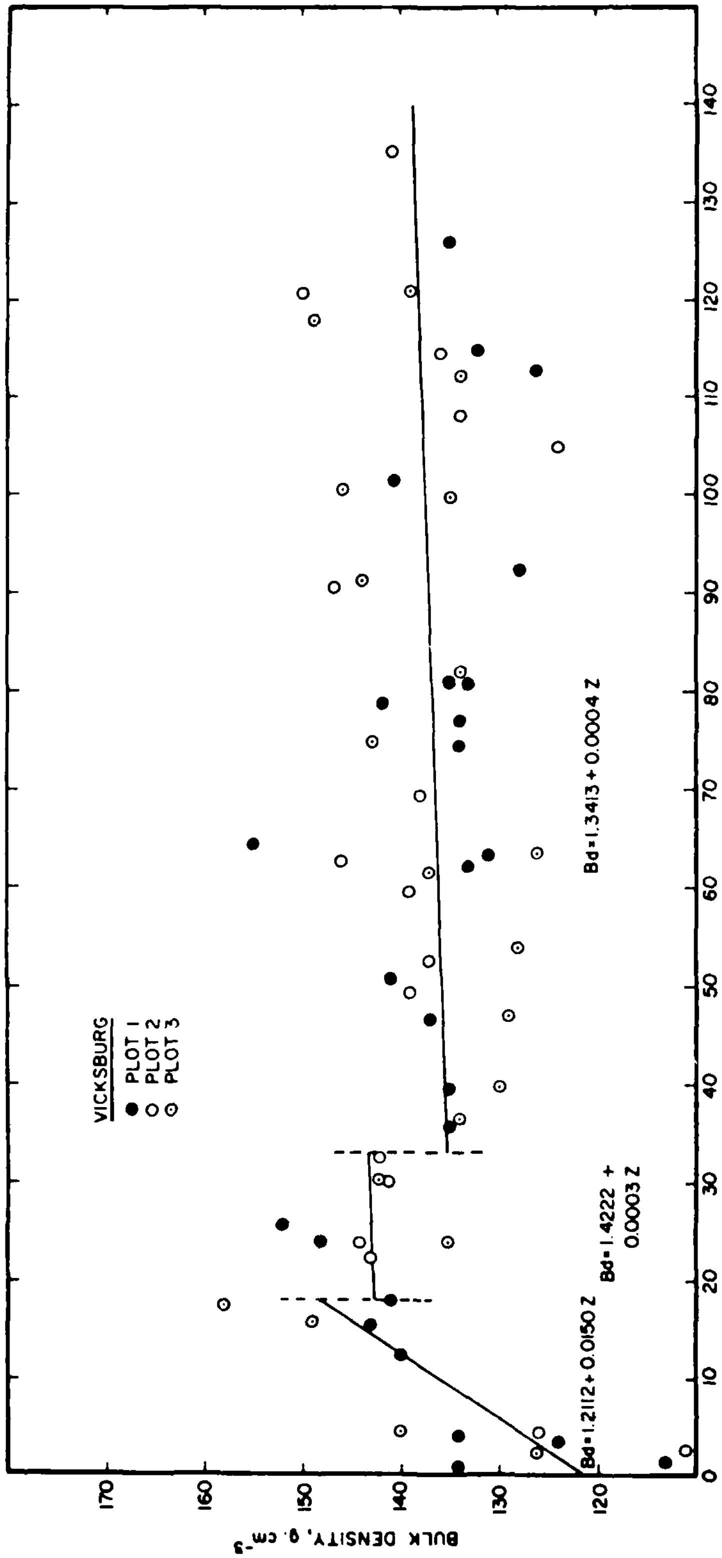
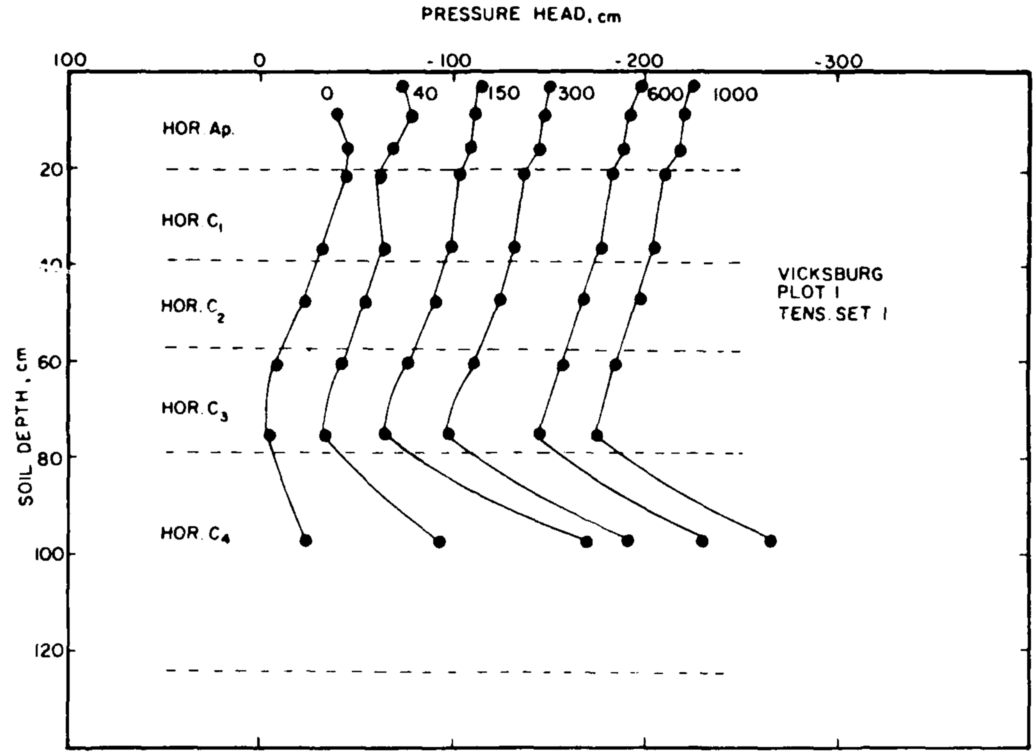


Figure 26 The bulk density-depth relationship for a Vicksburg soil.



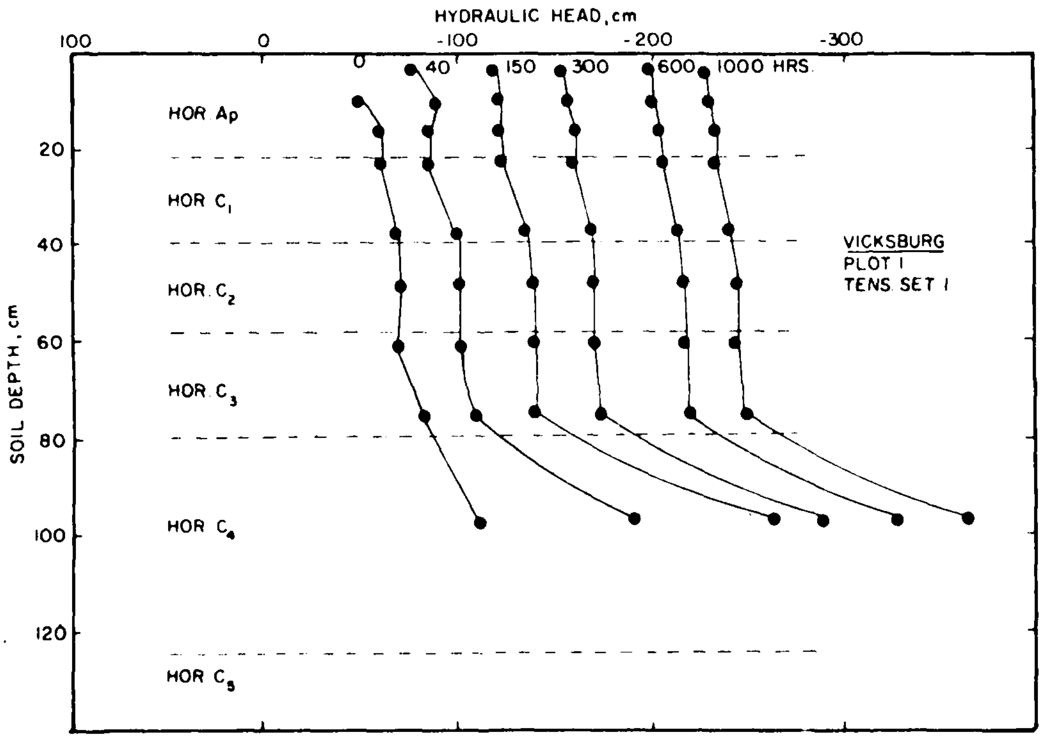


Figure 27 Pressure head and hydraulic head relationship for a Vicksburg soil (Plot 1).

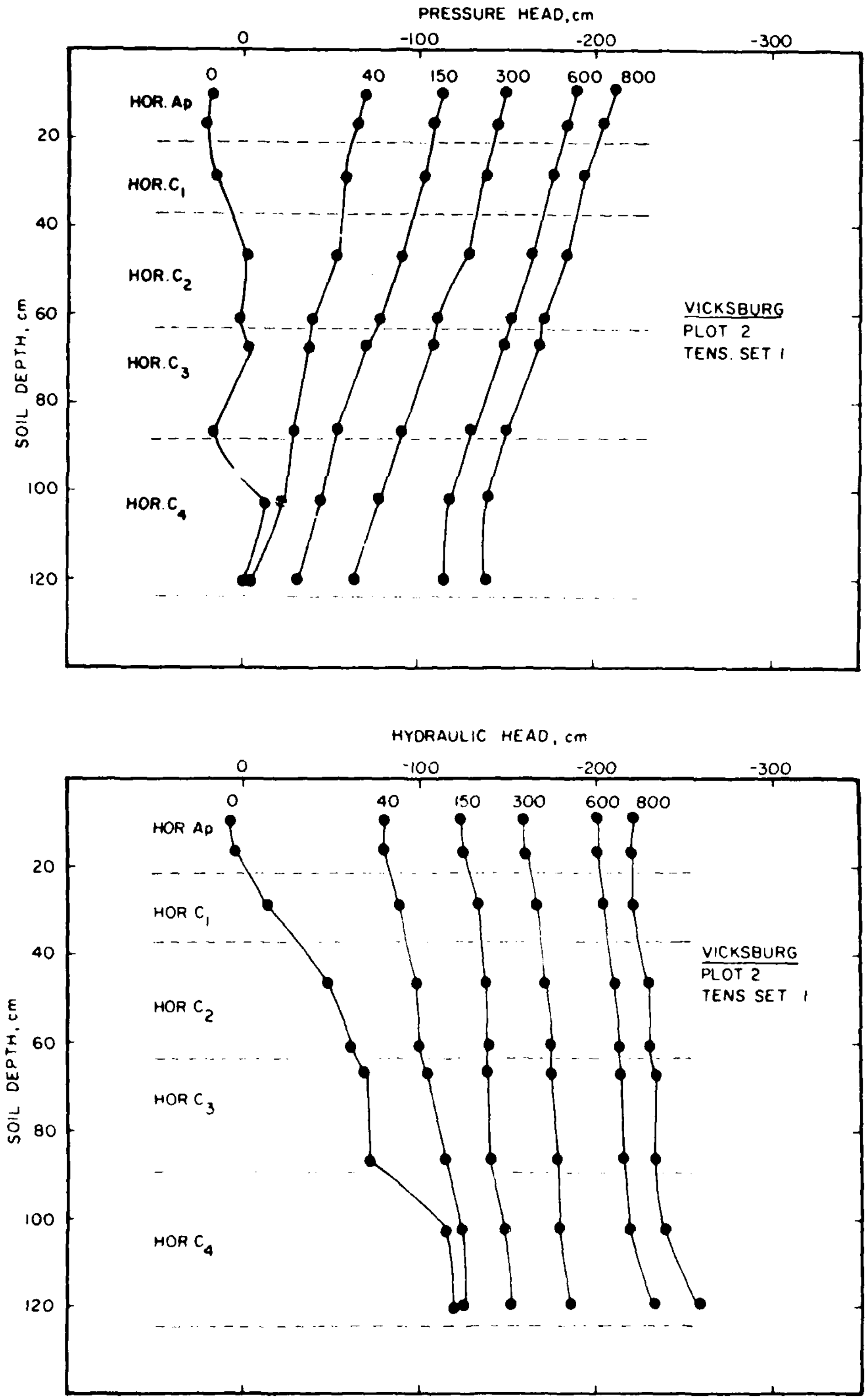


Figure 28 Pressure head and hydraulic head relationships for a Vicksburg soil (Plot 2).

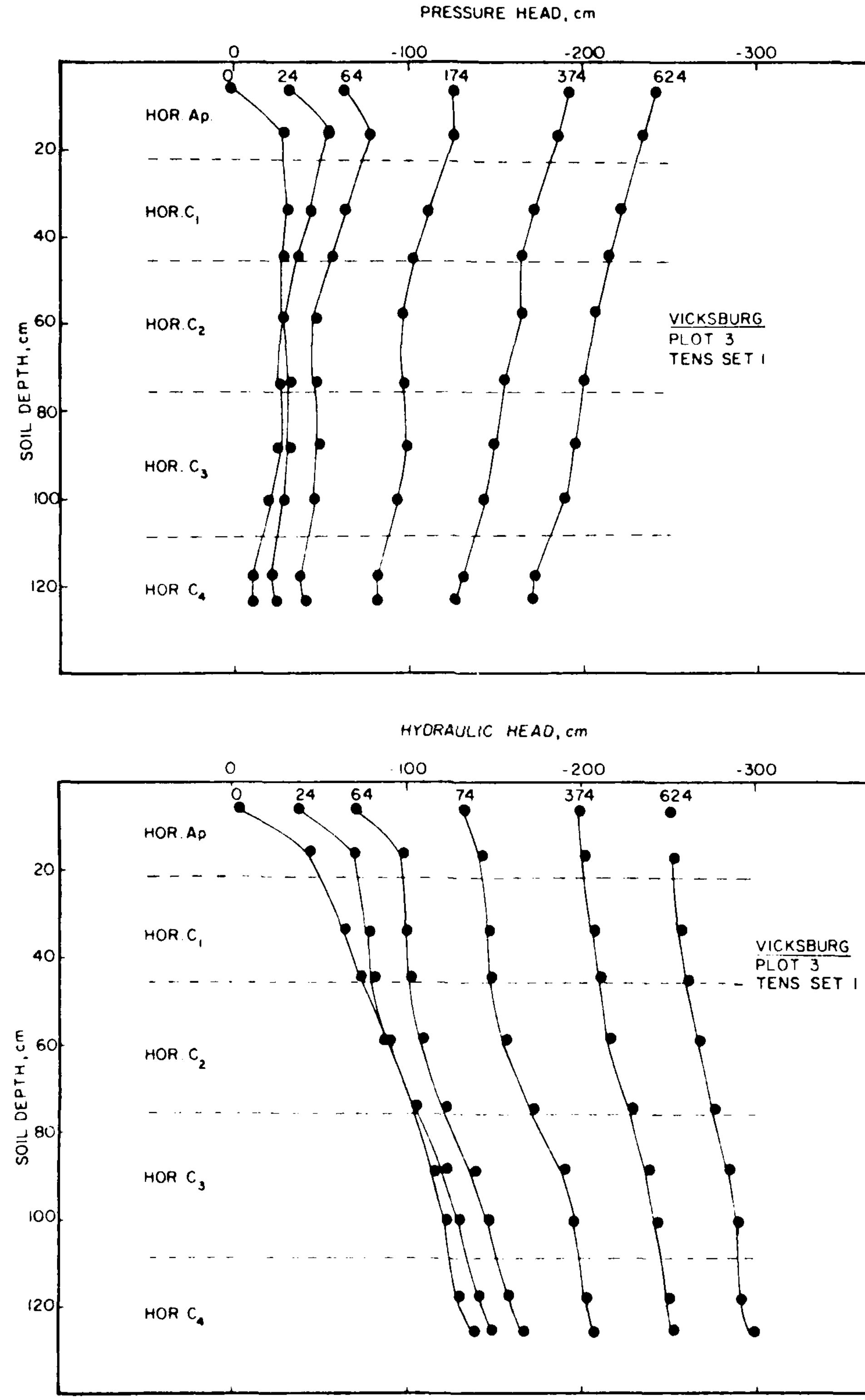


Figure 29 Pressure head and hydraulic head relationships for a Vicksburg soil (Plot 3).

integrated water content data to a straight line (Fig. 30). The water content data are based on neutron thermalization measurements. Differences between plots, as reflected by the slopes of the straight lines, were significant, but within reason given the textural variability between plots. In fact, the smallest drainage rate was noted for Plot 1, where abrupt changes in the hydraulic gradient were measured in going from horizon C3 to C4. Based on the average slope of the integrated water content versus depth relationship for the three plots, the rate of water loss to the deeper part of the profile was 7.9 cm^3 per 1 cm^2 of soil surface for a 122 cm thick profile during 1000 hrs. This amount of deep percolation under non-ponded surface conditions is substantially larger than that observed on the upland soils which previously were discussed. In fact, this amount represents about 19.6% of the total water content in the top 121.9 cm of the soil profile.

2.4 SUMMARY AND CONCLUSIONS

Water loss to deeper horizons was examined for three upland soils of aeolic origin and one alluvial bottomland soil, developed from wash-in soil material in Bluff line watersheds of northern Mississippi. Studies consisted of isolating a block of soil from the surrounding soil mass by vertical trenches with a cement coat applied to the vertical walls to prevent lateral water movement. The soil block was ponded with water and infiltration was allowed to proceed until a thoroughly wetted profile was obtained. The objective was to determine the internal drainage characteristics of these soils. In some cases, evapotranspiration was allowed to take place to permit a greater depletion of the soil water content for computations of hydraulic conductivity. The following conclusions can be drawn:

1. The upland soils showed extremely slow drainage characteristics. Little internal drainage was apparent in the Loring and Grenada sites. The presence of a fragipan was very apparent in the Grenada site as noted from tensiometer data. Such a pan was not detected with tensiometer information obtained for the Loring plots. On the other hand, the relatively small shift in tensiometer readings over the entire profile of the Loring plots made it impossible to detect differences in hydraulic gradients

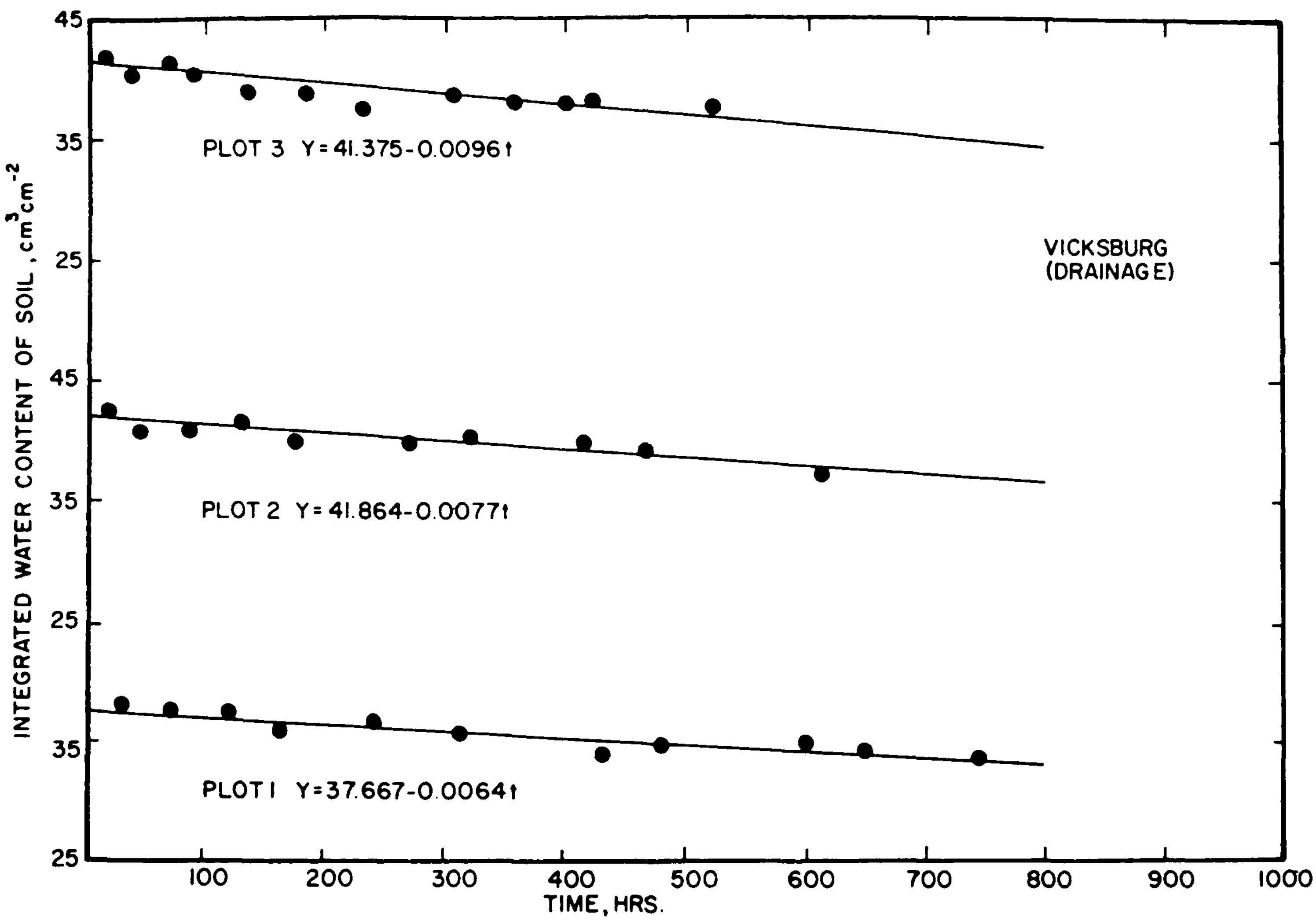


Figure 30 The integrated water content - time relationship for the Vicksburg site.

between horizons. In any case, both sites showed evidence of perched water tables for a sustained time period. Latter evidence was apparent from both pressure head data and standpipes.

The presence of fragipans or slowly draining soil horizons of loessial upland soils, therefore, has several consequences relative to channel stability. First, the poor or nonexistent internal water movement within the soil profile leads to a rapid filling up of the storage capacity of the profile. Runoff will take place quickly, surface flow will concentrate on specific locations on the upland slopes and conditions for rilling or gulley formation are enhanced. Secondly, lateral movement of infiltrated water or interflow in horizons above flow restrictive pans may lead to seepage at locations where channels or gulleys intersect with pans. At those points the possibility for a further deterioration of channel walls is enhanced.

2. The Memphis site did not have a fragipan. In fact, an increase in the hydraulic gradient was noted in the bottom part of the profile. On the other hand, water loss to deeper parts of the profile was small. Therefore, impact of this soil on the hydrologic response of watersheds and channel system will mainly be through runoff once precipitation has exceeded the infiltration rate and surface storage capacity.

   Most of the Memphis soils are found in the Brown Loam land resource area bordering the Mississippi Delta. There, the slopes are often steep and severely eroded, which is usually indicative of poor agricultural management in the past. Under these conditions, the greatest hazard, on this type soil, is sheet erosion and the potential for rilling and gullying by concentrated surface flow in the upper reaches of watersheds. Stabilization can best be met by proper land management, that is pasture and forestry.

3. The Vicksburg soil showed good internal drainage characteristics. On the other hand, there are other post settlement alluvial soils which are less well drained. However, most of these soils are found on bottomlands and are ideally suited for row cropping.

Because of the flat slopes, erosion hazards are small and sediment movement into channels may be inconsequential. Since this type soil usually is found at the base of steep slopes or along side channels (floodplains) its potential hazard results from overflow during severe weather conditions. Protecting the channel banks can best be accomplished by 10 - 20 feet border areas with controlled limited exit points for excess surface water.

3 INFILTRATION STUDIES

Before drainage and evaporation studies were commenced, attempts were made to investigate the infiltration characteristics of the Vicksburg and Memphis soils. Similar efforts for the Loring soils were not completed.

Infiltration experiments were carried out under ponded surface conditions. The procedure consisted of applying a known quantity of water to the plot surface. A wooden rim cemented on top of the concrete plot lining kept water within the confines of the plot boundary. Graduated scales, placed at preselected locations on the plot surface, permitted water level readings as infiltration proceeded. Water was added whenever the water level had decreased to near plot surface level. The depth of the water level varied between 0 and 5 cm.

Several complications were encountered in conducting field infiltration studies on the 2.13 x 1.83 m plots. (i) The non-level surface condition of most plots required partitioning of the plot surface into smaller units thereby creating unequal water levels within each sub-area. In nearly all studies the plot area was subdivided into 3 equal sub-areas. The differences in water levels between sub-areas may have caused unequal infiltration rates, especially during the early stages of infiltration. (ii) The upland soils exhibited some swelling capacity causing cracks in the concrete lining at some point during the infiltration process. Although cracks were immediately sealed, small quantities of water were lost on these plots due to seepage. However, the swelling characteristic of the loessial soils and the seepage effects confirmed the presence of positive pressure heads over most of the wetted part of the soil profile. Also, the swelling nature of this soil material suggests changes in the soil matrix, which may have profound effects on internal drainage and water movement of these soils. The traditional flow equation (4) therefore must incorporate changes in the $K(\Theta)$ and $\Psi(\Theta)$ relationships due to swelling charateristics. Naturally, this aspect was beyond the scope of this study. (iii) The sudden addition of large quantities of water (100 kg) to the plot surface often caused wash-outs at points of entry. The dispersed and suspended soil material eventually settled, thereby creating additional resistance to water intake.

The measured infiltration rates for the two plots of the Vicksburg soil are shown as a function of time in Figures 31 and 32. Figures 33 and

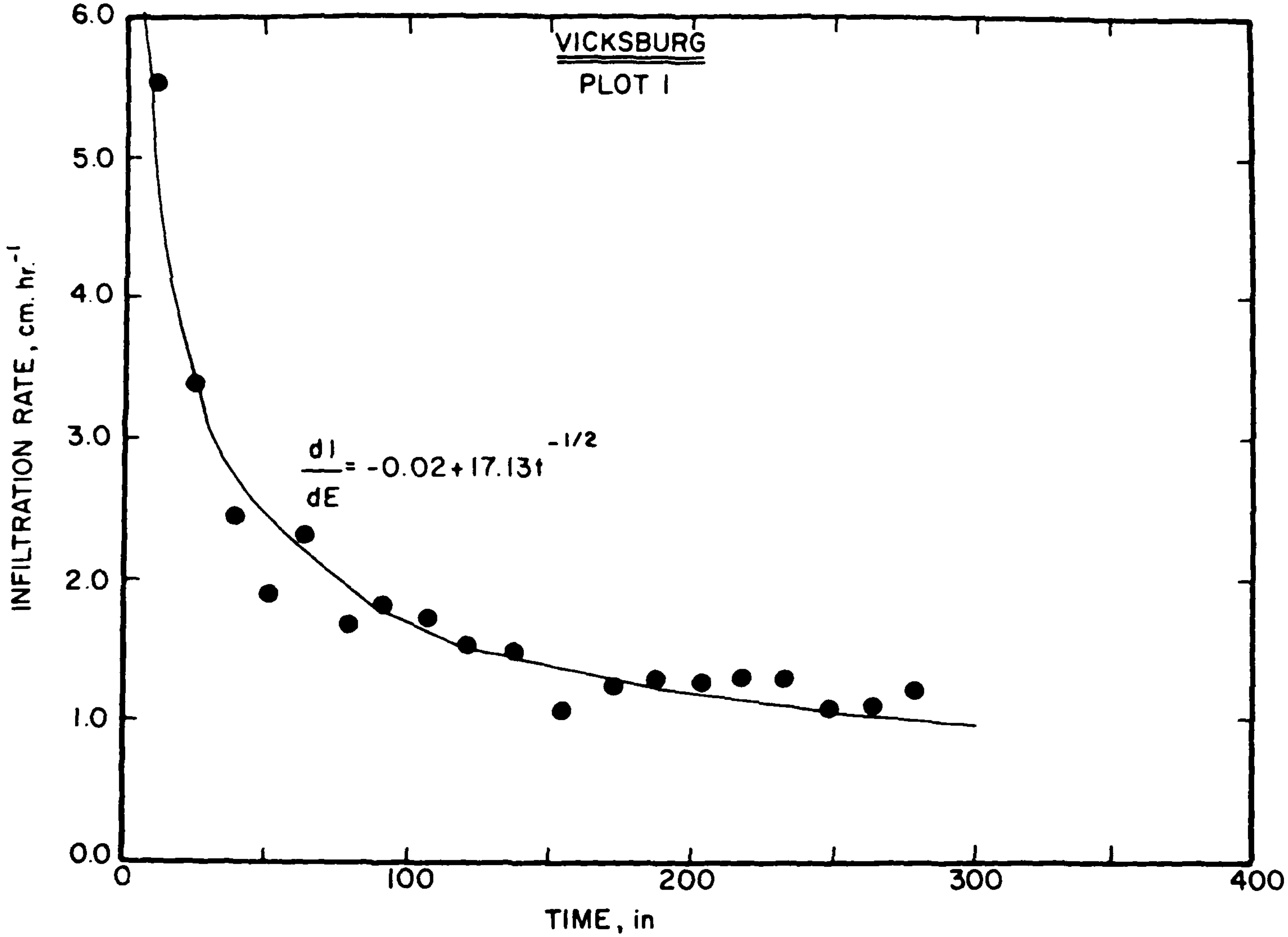


Figure 31 Observed infiltration rate *vs* time relationship for a Vicksburg soil (Plot 1).

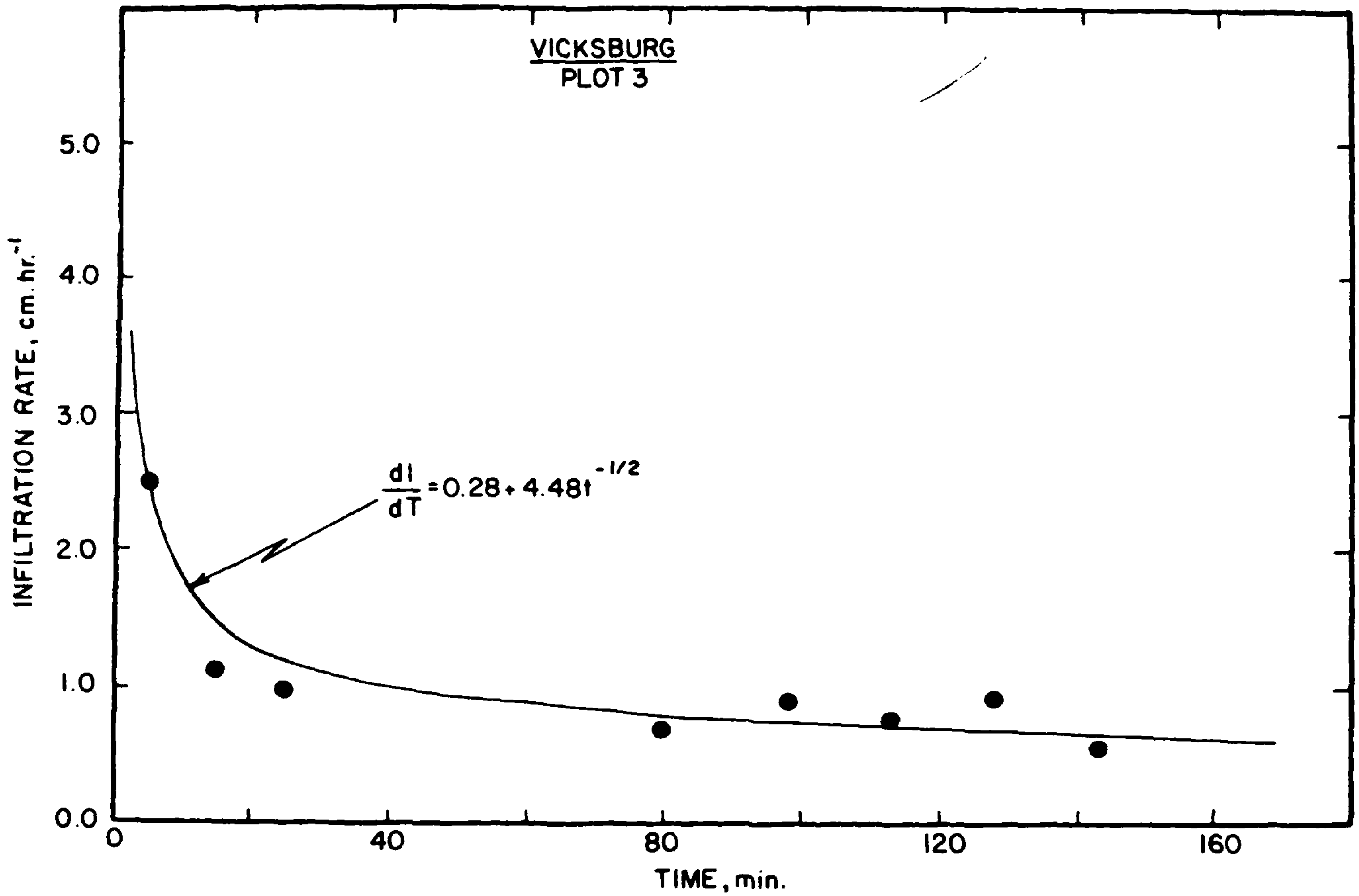


Figure 32 Observed infiltration rate vs time relationship for a Vicksburg soil (Plot 3).

34 show similar relationships for the Memphis soil. In all instances, a rapid decrease in the infiltration rate is noted from about 5 to 6 cm/hr initially to about 0.8 to 1.2 cm/hr for the Vicksburg soil and about 0.2 to 0.3 cm/hr for the Memphis soil after about 5 hours of ponding time. The appreciably smaller final infiltration rates for the Memphis soil as compared to the Vicksburg soil is due to the finer texture (Table 1) and the small, but noticeable, swelling capacity of the former soil. Latter characteristic was very apparent upon close examination of the partially dried outside walls of the excavated trenches. The presence of numerous fine cracks, which disappeared upon wetting, presented pathways for channel flow, which may contribute substantially to the initial abstraction of rain during a storm event. Naturally, channel flow on this soil will be of less significance if the soil profile is initially wet.

The data points were fitted to a differential form of a truncated series of terms containing powers of $t^{\frac{1}{2}}$.

$$\frac{di}{dt} = a + bt^{\frac{1}{2}} \tag{13}$$

where i is the cumulative infiltration, t is time, and a and b are constants. The relationship, usually referred to as the Philip equation, did not give a good fit for long times. On the other hand, the crude infiltration measuring technique, which was employed on this study and which is inherent in a field experiment of this nature, did not permit the necessary degree of refinement desirable for an adequate test of the functional infiltration curve for the above soils. Nevertheless, the approximate values obtained for rain infiltration under ponded conditions are indicative of the magnitude of water intake rates during the wet season, when runoff hazards are large.

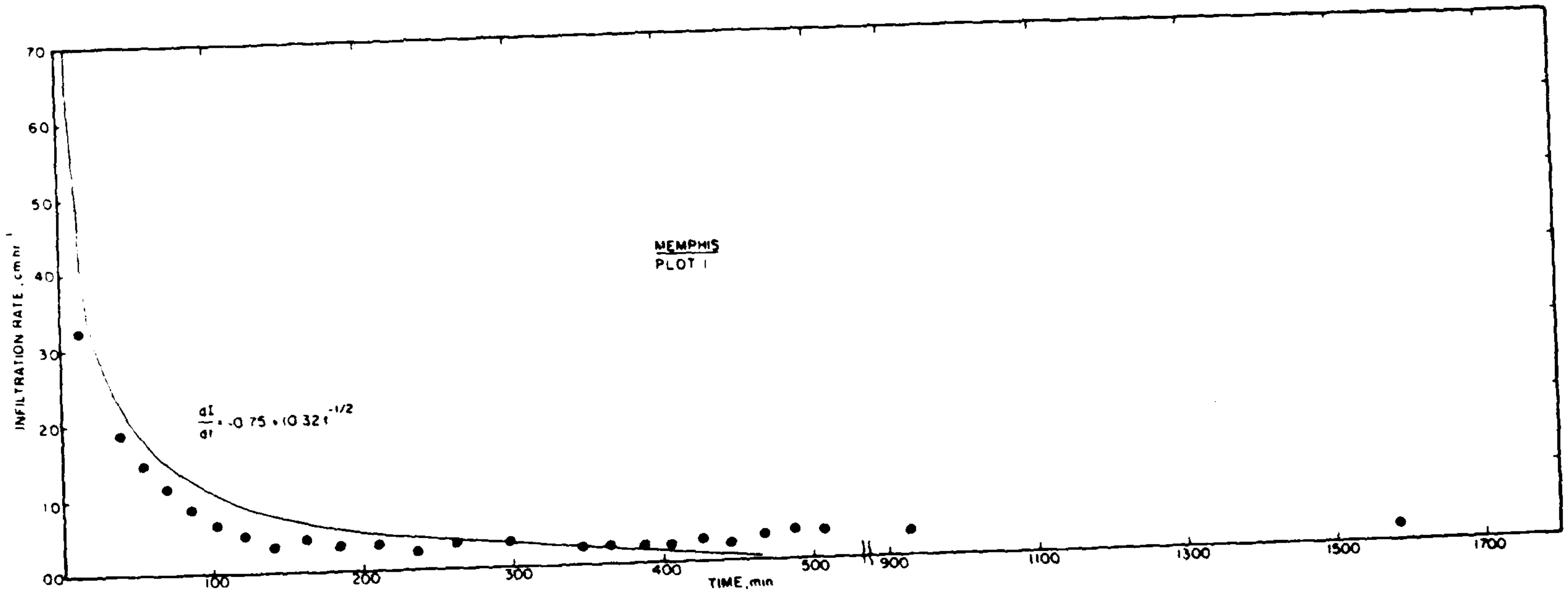


Figure 33 Observed infiltration rate vs time relationship for a Memphis soil (Plot 1).

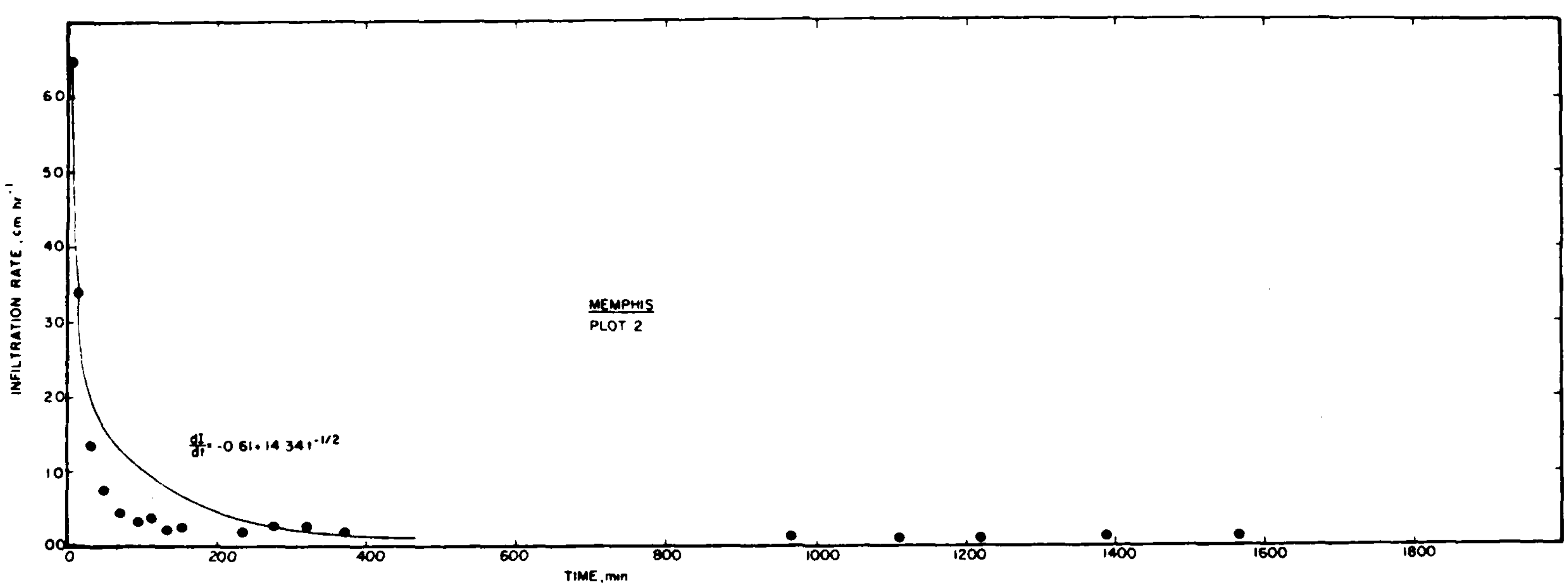


Figure 34 Observed infiltration rate *vs* time relationship for a Memphis soil (Plot 2).

4 SOIL MOISTURE MEASUREMENTS IN UNIT SOURCE WATERSHEDS

4.1 INTRODUCTION

As part of an effort to evaluate the hydrologic response of unit source watersheds in the Goodwin Creek catchments, limited research was conducted to follow the soil water regime for selected fields in uniform land use. The original objective was to measure the various components in a water budget relationship for a given area with special emphasis on the runoff and subsurface components. It was thought that a proper characterization of these components for the various land uses, management practices and topographic conditions would supplement channel flow measurement in the Goodwin catchment. Unfortunately, the information on the soil water regime reported in this section cannot be supplemented with runoff measurements conducted by other research units. Also, limited basic data were collected for computation of evapotranspirational losses for the research sites studied. Only during the 1980 crop growing season was ample meteorological data collected to estimate evapotranspiration losses using existing prediction models. However, plant data and meteorological information from surrounding weather stations may provide a basis for close estimates of 1979 transpiration losses.

Various forms of a budget relationship exist. However, all relationships can be reduced to one which has the following general form.

$$\Delta S = RF + I - RO - ET - SE \qquad (14)$$

where ΔS is the change of water storage in the soil, RF is rainfall, I is inflow (surface & subsurface), RO is runoff, ET is evapotranspiration, and SE is seepage. Seepage and subsurface inflow are usually the most difficult parameters to evaluate. However, to determine, <u>over time</u>, seepage losses to deeper soil horizons and/or lateral inflow and outflow (seepage out of channel wall), a continuous assessment of the soil water storage component is necessary. With this objective in mind, the water regime of several fields was followed during the 1978 through 1980 crop growing seasons. The specific objectives were: (i) to determine the variability of the soil moisture content within a row cropped bottomland field, and (ii) to provide a data base for evaluating the soil water component in a water budget equation for a typical unit source watershed.

4.2 PROCEDURE

4.2.1 Site Selection

Implementation of the above objective required field selections based on (simple) surface water boundaries, uniformity in slope, soil and cropping management, accessibility and cooperation of land owner or tenant.

The 1978-study was preliminary in nature and had as main objective the variability in soil water content during critical phases of soil water extraction by plants on typical bottomland conditions in the Goodwin watershed. The 1-acre research site was part of an approximately 10-acre field, located in the NW¼ of the SW¼ of Section 31, R6W, T9S Panola County, Mississippi. This 137.2 x 30.5 m site had been in continuous cotton with 1.02 m row spacings. The research site parallelled the main Goodwin Channel at about 10 m distance and consisted mainly of Ariel[1/] soil. Because of inadequate surface water boundaries, this field was abandoned in favor of another site in 1979 and 1980.

The 1979- and 1980-studies were conducted on a field located in the NE¼ of the NE¼ of Section 31, R6W, T9S, Panola County, Mississippi, opposite the Good Hope Baptist Church about 2.4 km north of Eureka Springs, Mississippi. This cotton cropped bottom land alongside the main Goodwin Creek channel was subdivided into two watersheds of about 0.8 ha each. In transecting the 200 x 40 m northern watershed from East to West, the soil changed from a Loring to an Ariel. The 152 x 61 m southern watershed consisted mostly of Ariel soil. Most of the surface soil appeared to be underlain by an old paleosol which reached a depth of about 1 m in localized areas of this field. However, no attempt was made to determine in detail the interfacial position of the surface soil and the paleosol.

4.2.2 Experimental Design

The 1978-study consisted of 24 observation points selected in a stratified block design in which 3 observation points were randomly chosen within each block. The 1979-study involved a total of 24 observation points of which 12 were located in each watershed again using a stratified block design of randomly selecting 3 observation points per block. For the 1980-study the number of observation points were reduced to 6 for each

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1/ Early classifications designated this soil to be a Collins and Vicksburg.

watershed. The observation points consisted of an access tube placed in the plant row for routine water content measurements. The 1979-study also included matrix potential measurements taken at depths of 15, 30, 60, 90, 120, and 150 cm at each observation point. Limited canopy and plant data were taken at each location. Matrix potential measurements had to be abandoned during the 1980-study due to frequent and irregular farming activities by the tenant farmer.

4.2.3 Measurements

Soil water content measurements consisted of gravimetric determinations and evaluations according to the neutron thermalization technique. Gravimetric determinations were made in 5 cm increments up to a depth of 30 cm for all studies and in 18 cm increments from 30 to 122 cm for the 1978- and 1979-studies. Neutron probe measurements commenced at 22.5 cm and increased in 15 cm intervals up to a depth of 99 cm (1978-study) or 122 cm (1979- and 1980-studies). The gravimetric water content values were converted to volumetric values using a bulk density-depth relationship developed for the 1979 research site. Bulk density data for the upper 30 cm were obtained by soil coring and for the 30 to 122 cm from a Troxler density depth probe. The latter data were corrected for antecedent soil moisture.

Soil water potential measurements were taken at frequent time intervals with mercury type manometers at 15, 30, 60, 90, 120, and 150 cm of soil depth. At each observation site for the 1979-study. However, these data have not yet been analyzed. Likewise, plant and canopy information, consisting of plant height, plant density, and photographic recordings made at 3.60 m height above soil surface for a 122 cm row length near each access tube have not been analyzed and will not be reported. Latter information, which was incidental to this project may provide a basis for computations of rainfall interception and rainfall energy dissipation as well as evapotranspirational water losses.

4.3 RESULTS AND DISCUSSION

4.3.1 1978-Study

The average water content of the soil profile is given in Figure 35 as a function of depth for six sampling dates. Figure 35 also shows the coefficients of variability as a function of depth. Several observations

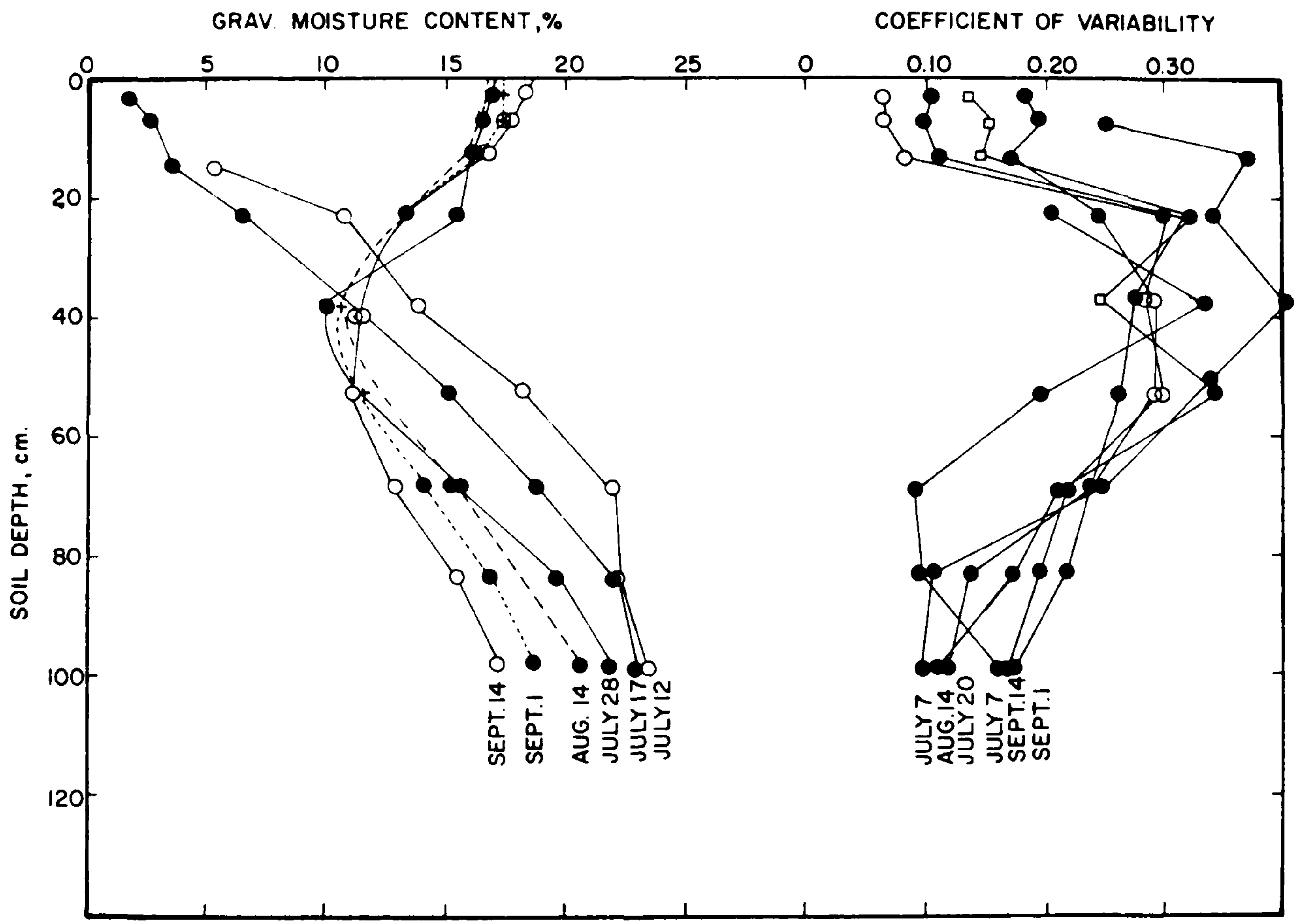


Figure 35 Average soil water content and coefficient of variability vs depth relationships for a bottom land field of Ariel soil cropped to cotton during the 1978 growing season.

can be made. (i) The moisture content at depths greater than 40 cm gradually decreased during the two months that measurements were performed, (ii) The moisture content in the upper 30 cm of the profile fluctuated appreciably depending on the relative influence of rain infiltration and evapotranspiration, (iii) The coefficients of variability of soil moisture observations reached maximum values between 20 to 50 cm of soil depth.

The hydrologic response of this field during the 1978 crop growth season exhibited the general characteristics of summer conditions where soil water loss by evapotranspiration dominates precipitation and infiltration effects. The systematic depletion of soil water at depths greater than 40 cm indicates the effects of water extraction by plant roots. However, the slight change in water content in the 50 to 100 cm depth during mid-July suggests a limited root density for this depth at this point in the growing season. However, appreciable depletion took place during the latter part of July and in August. During the entire sampling season, which ended on October 19, 1978, a net water loss was experienced in this part of the profile mostly through extraction by plant roots.

The effect of rainfall on recharge was marginal and was only felt in the upper 30 cm of the soil profile. Of course, the depth of rain infiltration depends on the rainfall amount, intensity, distribution as well as the hydraulic characteristics of the soil horizons. The recharge zone will be more apparent in those soils or zones where more soil water has been lost to evapotranspirational demand. In this study, the zone with fluctuating soil water content did not exceed 30 cm of soil depth.

4.3.2 1979-Study

The depth-bulk density relationship based on the average value of 24 data points for depths is given in Figure 36. This relationship shows the effects of a plow pan at 10 to 20 cm of soil depth, where an increase in bulk density is noted. However, the individual bulk density observations show appreciable scattering indicating substantial variation of density values over this field.

A summary of the water content measurements for the two watersheds studied during the 1979 season is given in Figure 37. The data representing the integrated water content of the soil profile up to depths of 30 and 122 cm, respectively, are based on mostly gravimetric determinations. These determinations were converted to volumetric values

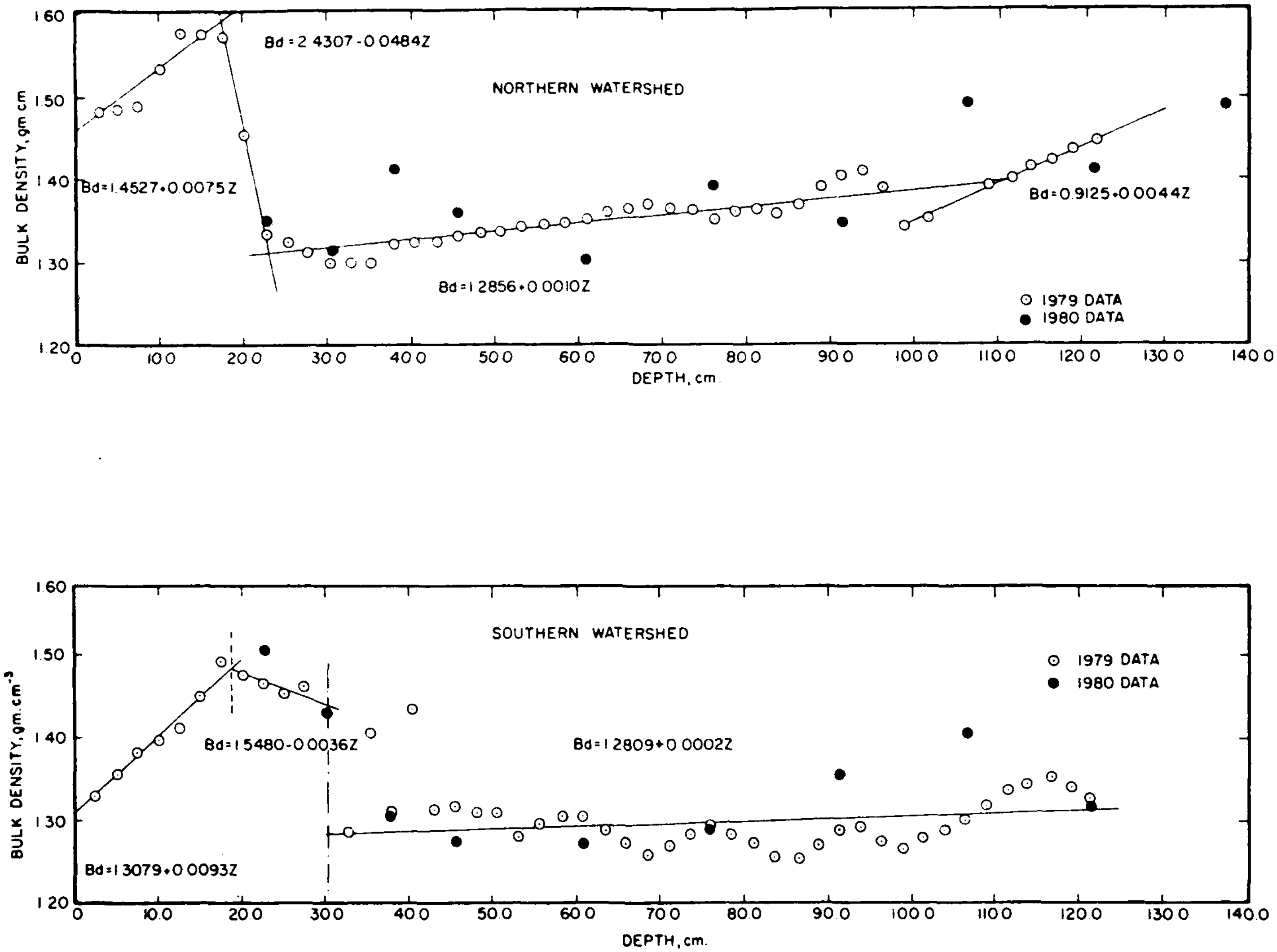


Figure 36 Depth-bulk density relationships for two bottom land watersheds in the Goodwin Creek basin.

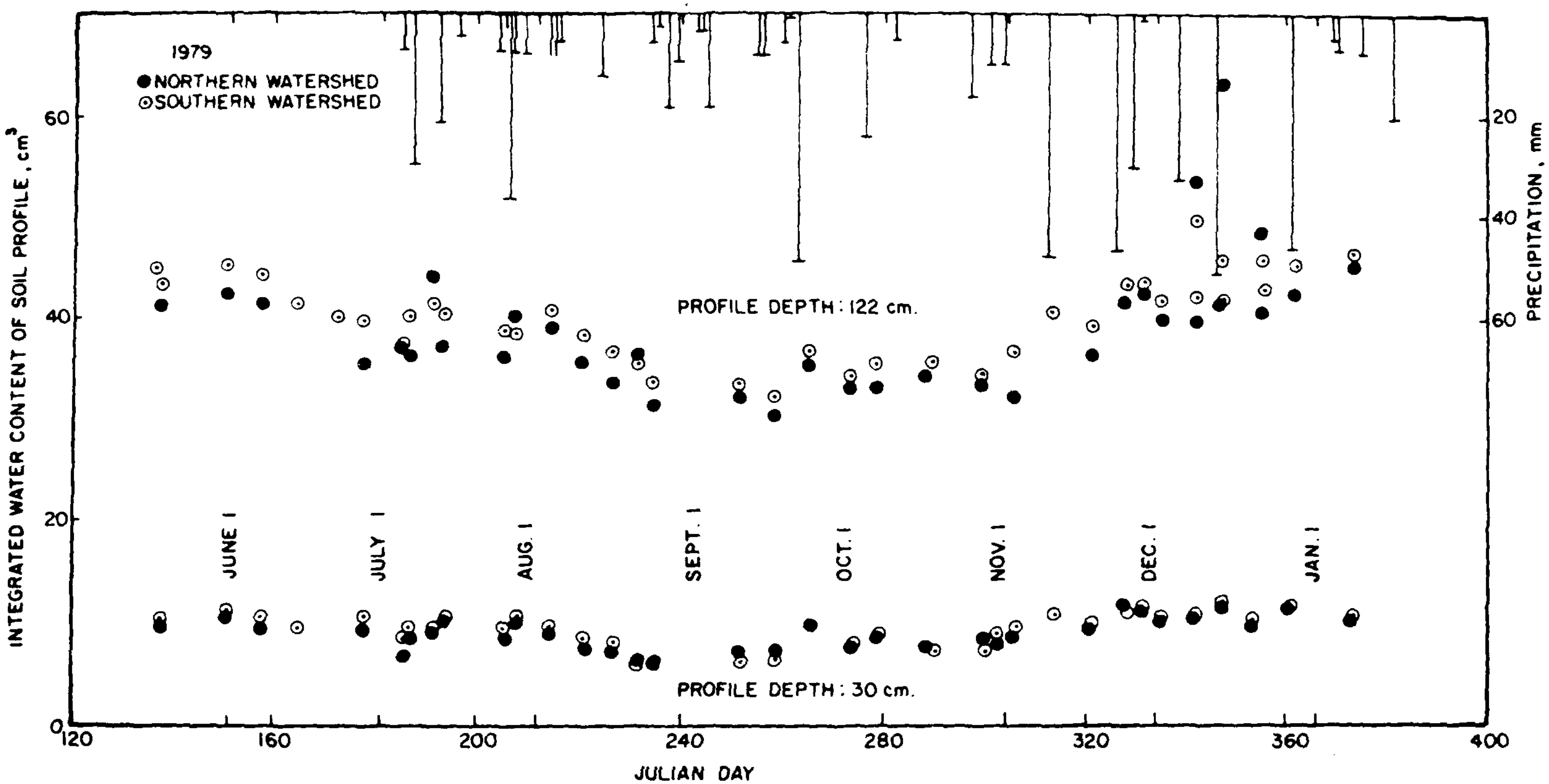


Figure 37 Integrated water content-time relationship for two watersheds in the Goodwin Creek basin.

using the bulk density relationship of Figure 36. Each data point represents an average value of as many as 12 observations for each watershed. Several observations apply: (i) The integrated water content of the northern watershed is appreciably smaller than that of the southern watershed. There is, however, some evidence that immediately following a storm event with appreciable precipitation, substantial larger water contents are measured in the northern watershed (e.g. storms of Dec. 9, 12, 22) as compared to those of the southern watershed. Differences in the integrated water content up to 30 cm of soil depth between watershed are minimal. (ii) The annual trend of soil water storage indicates a gradual decrease in the soil water content of the profile. This decrease commences at the end of May, 1979, and continues through June, July, and August and reaches a minimum in early September. The soil water content increases gradually in October and more rapidly in November and December, and reaches a maximum in January, 1980. Perturbations on this overall trend generally coincide with precipitation events.

The appreciable difference in the integrated water content of the soil profile between watersheds may be explained by the stratigraphy of this field. The eastern part of the northern field consists of a Loring soil which according to the SCS soil classification, has a "genetic" pan or different stratigraphic layer (Roxane formation) at about 75 cm of soil depth. This pan was however in evidence at about 30 cm of soil depth at the edge of this field. On the other hand, the presence of a hard-pan at about 90 cm of soil depth was noted toward the center but along the northern boundary of this watershed. Whether or not the latter pan represents the same or a different geologic formation has not been established. In any case, the impact of this pan on the water regime in the soil profile of this watershed is appreciable. The pan appears to act as a restrictive layer to water flow. Seepage of water under positive pressure potentials takes place either in a lateral direction (towards the channel wall) or to deeper geologic formations through local fissures or cracks ("tongues" of silty, but permeable material deposited between polygonally shaped impervious blocks). Following a storm event during the wet season, the soil profile above the pan "fills up" rapidly and releases excess water only very gradually. During seasons when the soil profile is partially dry, rain infiltration serves to replenish the depleted soil

water levels of the profile. The degree of soil water replenishment of course depends on the amount of infiltrated water and the degree of soil water depletion.

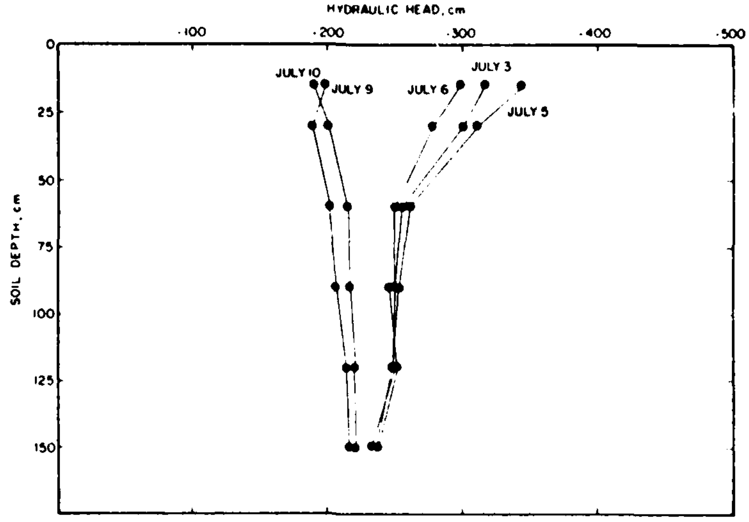
Water content measurements in the northern field up to a depth of 122 cm included reduced moisture levels in the pan itself, thereby yielding smaller values for the integrated water content of the soil profile of that watershed. Secondly, immediately following appreciable rainfall on an already wet antecedent condition the soil profile with the shallow pan tends to "fill up" rapidly, thereby yielding larger values for the integrated soil water content than a profile which has good internal drainage to deeper soil horizons. A third consequence may be reduced infiltration rates into the soil profile of the northern watershed, thereby yielding earlier and larger amounts of runoff than the southern watershed. Unfortunately, this observation could not be corroborated with runoff data.

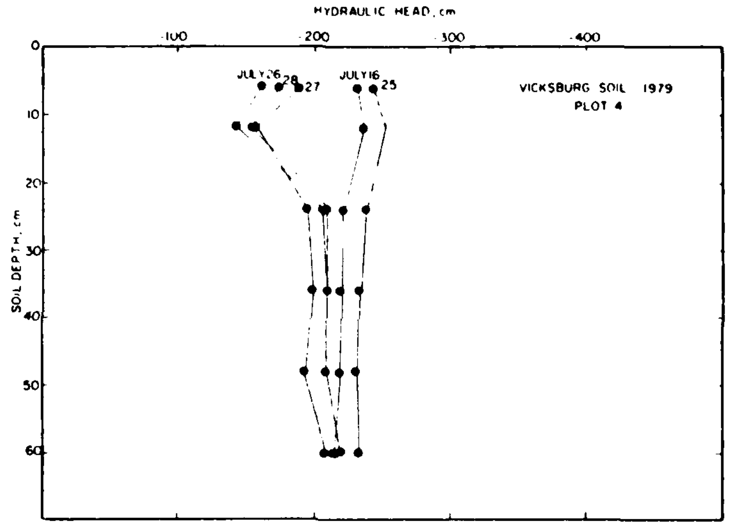
The effect of rainfall on soil profile replenishment is shown in Figure 38, where, for an observation point in the northern watershed, the hydraulic head-depth relationships are shown for a number of dates immediately before and after several storm events. The effect of rainfall is most strongly felt in the upper soil horizons. However, the appreciable shift in hydraulic head at 1.00 m depth one day following a rainstorm is indicative of the good hydraulic characteristics of this soil material. However, the data suggests the presence of a flow restrictive or root penetrative barrier (presumably a plow pan) at about 30 cm. Its impact on the water regime in the soil profile appears to be modest.

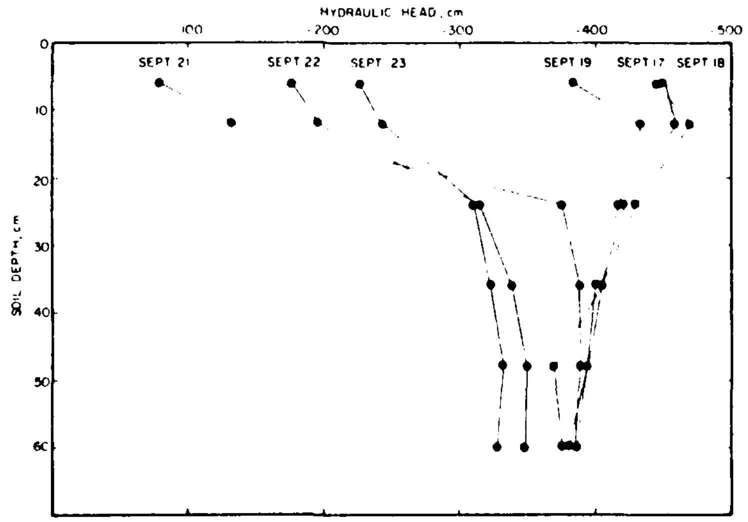
4.3.3 1980-Study

The 1980 water content measurements performed on the same field as the 1979-study, showed the same general pattern as those of the prior year (Fig. 39). However, 1980 was characterized by a severe drought. Rainfall events were few and far between. Total rainfall from June 1 to Sept. 15, as measured on this field, was 23.4 cm delivered in 10 storm events. However, a large amount of rainfall did occur at the end of September when 14.5 cm of rain fell in less than 3 days.

The effect of the drought on the soil water content of this field was indicated apparent by a severe reduction of the integrated water content of the soil profile. This reduction started earlier than that noted in 1979


HYDRAULIC HEAD, cm
SOIL DEPTH, cm
JULY 10
JULY 9
JULY 6
JULY 3
JULY 5


HYDRAULIC HEAD, cm
SOIL DEPTH, cm
JULY 26
28
27
JULY 16
25
VICKSBURG SOIL 1979
PLOT 4


HYDRAULIC HEAD, cm
SOIL DEPTH, cm
SEPT 21
SEPT 22
SEPT 23
SEPT 19
SEPT 17
SEPT 18

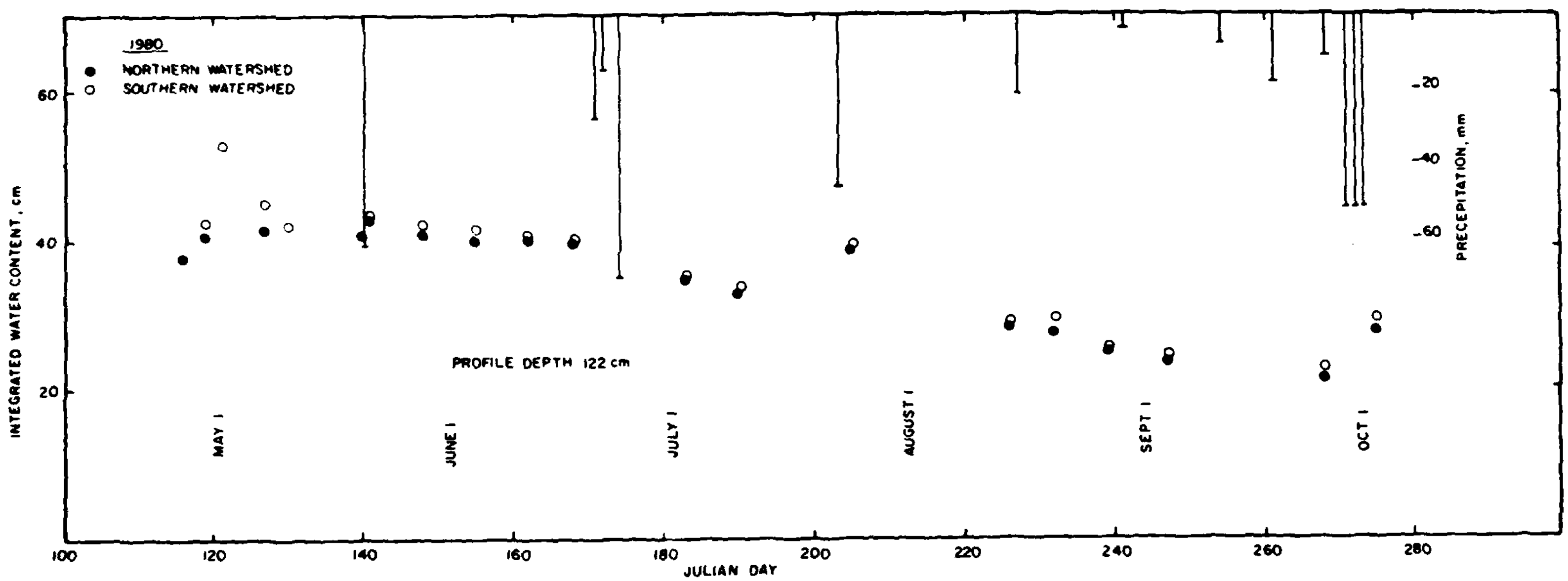


Figure 39 Integrated water content-time relationship for two watersheds in the Goodwin Creek basin during the 1980 summer season.

and reached a minimum value of about 21 cm^3 of water for about 122 cm^3 of soil depth. In spite of the severe moisture depletion of the root zone, especially in the upper part of the soil profile, the cotton canopy did not indicate wilting conditions. Apparently, evapotranspirational demands were adequately met by removal of soil water from deeper parts of the soil profile. Differences between watersheds were small. There was however a tendency for the southern watershed to contain a slightly larger amount of soil water than the northern watershed.

4.4 SUMMARY

Soil moisture measurements in unit source watersheds of cotton cropped bottom land showed appreciable decreases in soil water storage during the crop growth season. Soil water loss during this season was mostly by evapotranspiration. The decrease in the soil water storage was very appreciable during the drought of 1980. The soil profile was rapidly replenished with rainwater following a series of storm events in the fall of 1979. Also a three day storm event of 145 mm precipitation in the early fall of 1980 increased the soil water storage component by about 75 mm.

The presence of a pan was apparent from direct sampling activities as well as water content data. The surface hydrology of the watersheds appeared to be affected through low infiltration rates and increased runoff dates during storm events, with high antecedent moisture conditions. However, this conclusion could not be corroborated with independent runoff measurements. Secondly, it was surmised that lateral subsurface flow and seepage at channel walls may be experienced in those cases, where channels or gullies intersect flow restrictive layers.

5 ACKNOWLEDGEMENTS

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ADDENDUM

Soil Profile Descriptions[1]

1 Courtesy Mr. W. M. Morris, Jr., District Soil Scientist, Soil Conservation Service, Lafayette County, MS.

GRENADA SERIES

The Grenada series are moderately well drained soils with distinct A'2 horizons which have tongues or interfingers of gray silt loam extending into an underlying fragipan. These soils have formed in silty, loessial material on broad upland ridges and stream terraces.

Taxonomic Class: Fine-silty, mixed, thermic Glossic Fraguidalfs. Typical Pedon of Grenada Silt Loam, 1 percent slopes; 5 miles west of Oxford, Mississippi, on Highway 314; North 1800 feet in field. SW ¼, SW¼, Sec. 28, T7S, R4W.

Ap--0-8 centimeters, dark brown (10YR4/3) silt loam; weak fine and medium granular structure; friable; common fine and medium roots; strongly acid; abrupt smooth boundary.

Ap1--8-13 centimeters, dark yellowish brown (10YR4/4) silt loam; common fine faint brown (10YR5/3) mottles; weak fine and medium roots; strongly acid; abrupt smooth boundary.

B21--13-39 centimeters, dark yellowish brown (10YR4/6) heavy silt loam; weak to moderate medium subangular blocky structure; friable; few fine roots; few fine soft black concretions; strongly acid; gradual smooth boundary.

B22--39-52 centimeters, yellowish brown (10YR5/6) silt loam; common medium distinct dark yellowish brown (10YR4/6) mottles; weak to moderate medium subangular blocky structure; friable; few fine roots; pale brown silt coats on most faces of peds; common medium and fine black and dark brown concretions; very strongly acid; abrupt wavy boundary.

A'2--52-62 centimeters, very pale brown (10YR7/3) silt loam; common fine and medium distinct dark yellowish brown (10YR4/6) mottles; weak fine and medium subangular blocky structure; friable; slightly brittle; many fine vesicular pores; common fine and medium dark brown concretions; very strongly acid; abrupt irregular boundary.

B'X1--62-85 centimeters, dark yellowish brown (10YR4/6) heavy silt loam; many medium distinct light brownish gray (10YR6/2) and yellowish brown (10YR5/4) mottles; moderate coarse prismatic structure that parts into moderate medium sub-angular blocky structure; firm; compact and brittle; thick continuous clay films on faces of peds and prisms; tongues of gray silty material 1 to 2 centimeters

wide extending through the horizon; few vesicular pores; common fine and medium black and dark brown concretions; very strongly acid; gradual wavy boundary.

B'X--85-152 centimeters, yellowish brown (10YR5/6) silt; common medium distinct light brownish gray (10YR6/2) mottles; weak coarse prismatic structure that parts into moderate medium subangular blocky structure; firm; compact and brittle; patchy clay films on faces of peds and prisms; thick light gray seams extend into the horizon between prisms and few gray seams extend through the horizon; few black concretions; strongly acid.

LORING SERIES

The Loring Series is a member of the fine-silty, mixed, thermic family of Typic Fraguidalfs. They are moderately well drained soils with fragipans that formed in loess material on uplands.

Ap--0-8cm--Dark yellowish brown (10YR4/6) silt loam; weak fine granular structure; friable; common fine and medium roots; strongly acid; abrupt smooth boundary.

B21+--8-59cm--Strong brown (7.5YR5/6) light silty clay loam; moderate medium subangular blocky; friable; discontinuous clay films on faces of peds; common fine and medium roots; strongly acid; gradual smooth boundary.

B22+--59-91cm--Strong brown (7.5 YS5/6) silt loam; moderate medium subangular blocky structure; friable; patchy clay films on ped faces; thin discontinuous pale brown silt coats on faces of peds; few fine and medium black concretions; few fine and medium vescular pores; few fine roots; strongly acid; gradual irregular boundary.

Bx--91-122cm--Brown (10YR4/4) silt loam; common fine faint strong brown (7.5YR5/6) and common fine and medium pale brown (10YR6/3) mottles; weak coarse prismatic structure parting into moderate medium subangular blocky structure; firm; brittle and compact in 60 percent of cross section of prisms; grayish brown silty seams between prism; common medium and fine vescular pores and black concretions; strongly acid.

MEMPHIS SERIES

The Memphis series consists of well drained soils on loess covered uplands. This soil formed in silty material on ridgetops of 2 to 5 percent slopes.

Taxonomic Class: Fine - silty, mixed, thermic family of Typic Hapludalfs

Type Location: Memphis silt load, 2 to 5 percent slopes, eroded, about 4 miles north of Batesville, MS.

Ap--0-5 inches yellowish brown (10YR5/4) silt loam; weak fine granular structure; friable; many fine and medium roots; medium acid; abrupt smooth boundary.

B21t--5-27 inches strong brown (7.5YR5/6) silty clay loam; moderate medium subangular blocky structure; friable; discontinuous clay films on faces of peds; common fine and medium roots; few dark patchy coatings on faces of peds in lower part of horizon; few fine black concretions; strongly acid; gradual smooth boundary.

B22t--27-41 inches dark brown (7.5YR4/4) silt loam; moderate medium subangular blocky structure; friable; patchy clay films on faces of peds; common fine and medium roots; thin patchy silt coats on faces of peds; few fine black concretions; strongly acid; gradual smooth boundary.

B3t--41-50+ inches dark brown (7.5YR4/4) silt loam; weak medium subangular blocky structure; friable; patchy clay films on faces of peds; thin grayish silt coats on faces of peds; strongly acid.

VICKSBURG SERIES

The Vicksburg Series are well drained soils with dark brown silt loam A horizons and dark yellowish brown silt loam C horizons that have distinct bedding planes. These soils have formed in thick silty alluvial material mostly from loess origin on nearly level flood plains.

Taxonomic class: Coarse-silty, mixed, acid, thermic, Typic Udifluvents. Typical pedon of Vicksburg silt loam, 0.5 percent slopes; 7 miles southeast of Batesville, Mississippi; 1.25 miles north of Eureka Springs; 20 feet west of road in corner of field, NE ¼, NE ¼ Sec., 31, T9S, R6W.

Ap--0-18 centimeters, dark brown 10YR4/3 silt loam, weak fine granular structure; very friable; few fine roots; medium acid; abrupt smooth boundary.

C1--18-33 centimeters, dark yellowish brown (10YR4/4) silt loam; structureless; very friable; has bedding planes; strongly acid; abrupt smooth boundary.

C2--33-63 centimeters, dark yellowish brown (10YR4/4) silt loam; structureless; very friable; has bedding planes; has discontinuous fine sandy loam layers 1 to 2 centimeters thick and continuous fine sandy loam layer 2 to 4 centimeters thick; strongly acid; abrupt smooth boundary.

C3--63-81 centimeters, dark yellowish brown (10YR4/4) silt loam; structureless, very friable; has bedding planes; strongly acid; gradual smooth boundary.

C4--81-124 centimeters, dark yellowish brown (10YR4/6) silt loam; structureless, very friable, vew fine black concretions; strongly acid; clear smooth boundary.

C5--124-140 centimeters, dark yellowish brown (10YR4/4) silt loam, common medium distinct pale brown (10YR6/3) and light brownish gray (10YR6/2) mottles; structureless; friable; common fine and medium black and brown concretions; strongly acid.

Range in characteristics: Thickness of horizons range from 4 to 10 centimeters from side to side and from plot to plot.

DAT

FILM